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THE ALL-AMERICAN CANAL

REPORT

OF

THE ALL-AMERICAN CANAL BOARD

Dr. ELWOOD MEAD W. W. SCHLECHT
C. E. GRUNSKY

ON

A CANAL LOCATED ENTIRELY WITHIN THE UNITED STATES
FROM THE COLORADO RIVER AT LAGUNA DAM
INTO THE IMPERIAL VALLEY, CALIFORNIA

JULY 22, 1919

TOGETHER WITH THE

REPORT OF THE ENGINEER IN CHARGE OF SURVEYS AND EXAMINATIONS

PORTER J. PRESTON

JUNE 17, 1919

DEPARTMENT OF THE INTERIOR

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Dr. ELWOOD MEAD W. W. SCHLECHT
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LETTER OF SUBMITTAL.

San Francisco, Calif., *July 22, 1919.*

To the Secretary of the Interior and the
Board of Directors, Imperial Irrigation District.

Sirs: There is submitted herewith our report, as required by the terms of the agreement between the Secretary of the Interior and the board of directors of Imperial Irrigation District, bearing date February 16, 1918, which provides for surveys and studies of the problem of constructing a canal, located entirely within the United States, from Colorado River, at the Laguna Dam, into the Imperial Valley, Calif. A preliminary report transmitting a cost estimate was submitted in December, 1918. On the basis of later and more complete information, the earlier estimates have been revised for this final report, and as required by the terms of the agreement, the larger problems of the Colorado River are therein discussed.

It is hoped that means will be found to put into effect at an early day the recommendations made by this board.

Respectfully,

Elwood Mead,
W. W. Schlecht,
C. E. Grunsky,
All-American Canal Board.

CONTENTS.

PART I.

REPORT OF ALL-AMERICAN CANAL BOARD.

Page.

Organization and duties of the All-American Canal Board.................... 7
The present situation on the lower Colorado River.................... 8
The navigability of Colorado River.................... 13
Operations in Mexico.................... 14
Some channel characteristics and the river discharge.................... 16
The Imperial Valley and its development under irrigation.................... 17
The Yuma project.................... 21
The Colorado River as an international boundary.................... 21
Water conservation by storage.................... 23
The silt problem.................... 24
The flood menace.................... 26
Drift.................... 31
The drifting sand.................... 31
The canal capacity.................... 34
Methods of construction and unit costs.................... 36
The canal headworks at Laguna Dam.................... 39
The canal from Laguna Dam to the siphon drop.................... 42
The canal from the siphon drop to Pilot Knob.................... 44
Canal location at Pilot Knob and thence westerly.................... 44
Completion of survey.................... 47
Power development.................... 47
Distribution of cost and of returns from power sales.................... 50
The control and operation of works in which the Yuma project and the Imperial Valley are jointly interested.................... 56
Cost estimates.................... 57
Plan of procedure.................... 62
Recommendations.................... 63
Appendix—Agreements between Secretary of Interior and Imperial Irrigation District.................... 65
    Agreement of February 16, 1918, for appointment of board and surveys.. 65
    Agreement of October 23, 1918, for extension of Imperial Canal to Laguna Dam and committing the district to construction of All-American Canal.................... 67

PART II.

REPORT OF ENGINEER IN CHARGE OF SURVEYS AND EXAMINATIONS.

Introduction.................... 72
Preliminary report.................... 73
Earlier surveys.................... 73
Surveys.................... 74

Page.
Irrigable acreage........ 75
Water duty........ 75
Blow sand........ 78
Classification of material........ 80
Canal sections and capacities........ 81
Canal structures........ 83
Unit costs........ 84
Estimate of cost........ 84
Power development........ 97

LIST OF TABLES.

The discharge of Colorado River........ 17
Reservoir sites in Colorado Basin........ 24
Silt content, Colorado River........ 26
Fineness of sand from the sand hills........ 33
Irrigation water demand by months........ 35
Cost estimates, summary and analysis........ 58
Water deliveries, Yuma project........ 76
Unit costs........ 84
Cost estimates, details........ 86
Estimated cost of power development........ 98

LIST OF EXHIBITS.

EXHIBIT A. General map all-American canal.
B. Profile all-American canal.
C. Laguna Dam, proposed changes.
D. Typical sections at south end of sand hills.

THE ALL-AMERICAN CANAL.

(From Colorado River into the Imperial Valley, Calif.)

Part I.

REPORT OF THE ALL-AMERICAN CANAL BOARD.

By Dr. ELWOOD MEAD, W. W. SCHLECHT, and C. E. GRUNSKY.

ORGANIZATION AND DUTIES OF THE ALL-AMERICAN CANAL BOARD.

This board has been appointed under the provisions of an agreement bearing date February 16, 1918, between the Secretary of the Interior and the Imperial irrigation district of California, of which a copy has been attached hereto. (See Appendix, p. 65.)

The United States Reclamation Service has placed its records and office facilities at the disposal of the board and has submitted the designs for the proposed power plants, which, while remaining subject to any modification that may later be found necessary to adapt them to the peculiar conditions of a canal from Colorado River, have been made the basis of the cost estimate relating to the development of power.

This board is required to submit "specific conclusions and recommendations as to the future policy." It is in compliance with this requirement that the following discussion of the problem of the lower Colorado River, which involves not only the construction of a canal, but also protection against a flood menace from beyond this country's boundary, is now presented. The situation deserves the best thought not only of those who may be called on to perfect a project for the better and more complete irrigation of the Imperial and Coachella Valleys, but also of those who may be charged with the planning and execution of some arrangement with Mexico whereby the United States' interests will be adequately protected. The board ventures to hope that its conclusions may be of some assistance in bringing about a satisfactory agreement between the two countries.

For more complete information relating to the Colorado River and the problems relating to irrigation therefrom, to its floods and problems connected therewith, and to the possibilities of regulating its flow to some extent by the construction of storage reservoirs, reference should be had to the following publications and compilations:

Report on the Utilization of the Waters of Colorado River for Irrigation and its Relation to the Imperial Valley, California, by C. E. Grunsky, consulting engineer in the United States Reclamation Service. Dated June 30, 1907, and addressed to Hon. James Rudolph Garfield, Secretary of the Interior. (S. Doc. No. 103, 65th Cong., 1st sess.)

Colorado River and its Utilization, by E. C. LaRue (Water Supply Paper No. 395, U. S. Geological Survey.)[1]

The Lower Colorado and the Salton Basin, by C. E. Grunsky (Transactions American Society of Civil Engineers, Vol. LIX, pp. 1–51. Dec., 1907).

Irrigation and River Control in the Colorado River Delta, by H. T. Cory (Transactions American Society of Civil Engineers, Vol. LXXVI, pp. 1204–1453. Dec., 1913).

Also the unpublished very comprehensive compilation of material bearing on the Colorado River by John T. Whistler, of the United States Reclamation Service, and on file in the Reclamation Service offices at Washington, Denver, and Yuma.

THE PRESENT SITUATION ON THE LOWER COLORADO RIVER.

This board can not adequately present and discuss the problem of an all-American or high-line canal from the Colorado River into the Imperial Valley without reviewing briefly the present situation on the lower Colorado River, which in many respects is unique and exceptionally complex. The factors which are responsible for this condition are to be sought in the physical characteristics of the river and of the delta cone which it has pushed from Yuma southwesterly into Mexico; the unfortunate location of the international boundary line; and the human agencies which have disturbed and modified the river's natural delta channels and delta conditions generally, and have given the river an opportunity to run wild.

The principal facts to be considered in any discussion of the problem of the lower Colorado River are presented in the following pages.

The Colorado River is essentially a United States river, but it becomes an international boundary at Pilot Knob, about 8 miles below Yuma. Its outfall into the Gulf of California is wholly on Mexican territory. For about 20 miles below Pilot Knob the river is the boundary between the United States and Mexico. Arizona lies to the east and Lower California to the west of this part of the river. The water of the lower Colorado River, or more particularly the water which flows in the river past Yuma, has its source in seven States. A small portion only of the watershed of the Colorado above Yuma, possibly 1,500 square miles out of a total of 244,000 square miles, is in Mexico, but in a region of light rainfall with almost negligible effect upon the river's flow at Yuma. Practically the entire flow of the river originates, therefore, within the United States. The records of the United States Geological Survey indicate that since 1902 this flow at Yuma has ranged from a minimum of 8,000,000 acre-feet to a maximum of 26,000,000 acre-feet and has averaged somewhat more than 17,000,000 acre-feet per annum. At the lowest stage in the fall and early winter months the discharge of the river at Yuma may drop occasionally to 3,000 second-feet, though the ordinary low-water stage has usually been about 4,000 second-feet. At its highest stages the discharge is reported to have exceeded 200,000 second-feet. The ordinary summer maximum flow for the period covered has averaged 94,000 second-feet.

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[1] This paper contains much valuable information relating to Colorado River and its tributaries and gives an estimate of the possible ultimate extent of irrigation from this stream. It contains a good reference to publications describing the river and early explorations thereof.

There have been times, confirmed by Indian traditions, when the Colorado River delivered its water into the Salton Basin instead of as at present into the Gulf of California. This basin was then an inland sea with a surface area of nearly 2,000 square miles, embracing all of what is now known as Imperial and Coachella Valleys. This sea extended from the Volcano Lake in Lower California northwesterly into California to a point a few miles to the northward of Indio. The greatest depth of this sea was about 320 feet. Its margin is well marked by a beach line which can readily be traced at many points on both sides of Salton Basin.

For more than 400 years, and probably for a period of more than 500 years (it may have been considerably longer), the Colorado River has discharged uninterruptedly into the Gulf of California, except only for about one year, 1905 to 1907, when its discharge was temporarily inland into the Salton Sea.

The Colorado River at and below Yuma is a muddy stream flowing in a broad bed of sand. The sediment and sand which it transports in suspension and as a bed load if uniformly distributed would cover about 90,000 to 100,000 acres 1 foot in depth on an average per annum. The Gulf of California at one time in the past extended far into California, embracing most of the area now known as Salton Basin, of which the larger portion lies below sea level. The sand and sediment brought down by the river has built up a delta cone whose upper end or apex may be considered to be at Yuma and which spreads out fan-shaped to the south and west, thence with a gentle slope toward the north, far into California. It rounds the southern termination in Mexico of the mesa formation which flanks the right bank of the river. This delta embraces what is known as Yuma Valley on the east side of the river, a small part of Sonora near the upper end of the Gulf of California, the portion of Lower California lying between the river and the Cocopah Mountains except a small area of mesa and sand-hill formation which projects over the international boundary from California and except the detrital slope at the base of the Cocopah Range, and also the region at one time known as the New River country in California and now known as the Imperial Valley. This delta cone was built across the ancient Gulf of California and cut off the Salton Basin from a connection with the gulf. Its crest follows a line slightly convex to the south from a few miles below Pilot Knob to the base of the detrital slope of the Cocopah Mountains west or northwest of Volcano Lake. Volcano Lake, now practically obliterated by deposits of silt, was a flat depression on top of the broad deltaic ridge, from which there were outlets carrying water at the river's periodic high stages both toward the south into the gulf region and toward the north into the New River country.

Under the conditions as modified by human agency, the river has, as noted above, broken from its bed in recent years, first in 1905 (and 1907), near the apex of the delta, and again in 1909, 20 miles farther south. The river was turned back into its proper channel after breaking from its course near the head of the delta. The change made in 1909 put the river on the course toward Volcano Lake, as it flows to-day. Fortunately the point at which this change occurred at the head of the Abejas or Bee River, is so far downstream that by means of levees the river could be and has been prevented from taking a course down the north slope of the delta cone into Imperial Valley. The river must be kept on a course to the south, with outfall into the Gulf of California, if disaster to the Imperial and Coachella Valleys is to be avoided. The river on its original course was as far east at certain points below Arizona as it could go. Its course brought it hard up against the first, second, and third mesas in Sonora. The only change of alignment, in a large sense, above the lowest of these points which the river could make was through a breach of its right or west bank below the California boundary and, therefore, upon Mexican territory.

The elevation above mean sea level of the apex of the delta cone of Colorado River near Yuma is about 125 feet. At the south boundary line of Arizona, being near the point where the river abandoned its original bed in 1909, the general elevation of the river bank land is about 88 feet. Thence westerly the ground falls toward Volcano Lake about 50 feet in a distance of 30 miles. From Volcano Lake there is a gradual fall toward the north into Imperial Valley and toward the south into the gulf region. The lowest point of the valley floor along the south boundary line of California, not considering the deeply eroded barranca of New River, is about 6 miles west of Calexico, about 11 feet below sea level. El Centro is about 50 feet and Brawley about 110 feet below sea level.

In its natural condition, before being affected by human activities, the Colorado River below Yuma at its flood stages sent water overbank to the right and left. Some of the right-bank flood water flowing down the slopes of the delta cone collected in channels which dropped off toward the north. Notable among these channels is the Alamo River, at one time also known as Salton or Carters River. Other flood water, collecting in the Paredones and Saiz Channels, went southwesterly and westerly into the Volcano Lake region, and still other water escaping from the river lower down was collected by the Abejas, the Pescadero, and other southwesterly channels, and ultimately found its way through the Hardy Colorado into the Gulf. The main portion of the delta was thus well watered. The extent of annual flooding varied, of course, with the magnitude and duration of the flood flow As a consequence of this well-watered condition the growth of trees, brush, weeds, and grasses was rank; and this vegetation retarding, as it did, the widely extended sheets of flood water that went from the river over its broad flat banks, became a barrier to any sudden change of the river's alignment and gave assurance that if left undisturbed the river would have long remained on its original course to the Gulf.

That this condition no longer obtains is quite fully set forth elsewhere in this report. To a large extent the natural obstacles to a free overbank flow of water westerly and northerly into the Imperial Valley have disappeared and artificial barriers are now required to hold the flood flow of the river in check.

The Colorado River must, at an early day, be put on a direct course to the Gulf of California. The burden of maintaining barriers against the waters from the Volcano Lake region is increasing from year to year and the cost thereof should not fall upon the Imperial Irrigation District alone. Other interests are protected as well in Mexico as in the United States. The control of the lower Colorado will remain an international problem as long as the delta of the river is divided between the United States and Mexico.

Furthermore, the menace from the floods of the Colorado is such a serious menace to so large an area in the United States and to so many people and to so much property that the protection should not have to be done as at present by a local district through a foreign agency.

The Imperial Irrigation District is the successor to the California Development Co. The district is a public or quasi municipal corporation organized under the laws of California, and has bought the canal properties formerly owned by the California Development Co., includ-

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NOTE.—For a full account of the river's change of course in 1905 and the successful operations which resulted in the river's being returned to its original channel, see the paper by H. T. Cory, the engineer in charge of this work as published in the Transactions of the American Society of Civil Engineers, Volume LXXVI, pages 1201 to 1571. See also a paper by C. E. Grunsky in Volume LIX, page 1, of the Transactions, and the report by C. E. Grunsky to the Secretary of the Interior published as Senate Document No. 103 of the Sixty-fifth Congress, first session.

ing all the shares of stock in a Mexican company, which is the agency through which the district conducts all necessary operations in Mexico.

The area of the district is about 586,000 acres. Irrigation has already been extended within the district to 392,000 acres (this was the area served with water in 1918). No cultivation is possible without irrigation. The mean annual rainfall in Imperial Valley is less than 3 inches. Some idea of the extent of development in the Imperial Valley will be obtainable from the following facts and figures: Within the district are the towns of Calexico (4,500 inhabitants); El Centro (7,500 inhabitants); Imperial (2,500 inhabitants); Holtville (2,500 inhabitants); Brawley (4,800 inhabitants); besides other towns and places such as Calipatria, Niland, Seeley, Heber, and Dixieland. The total population of the California portion of Imperial Valley is estimated at 55,000. This does not include the population of Coachella Valley. The Southern Pacific Railroad enters the Coachella Valley at the north and, dipping down into the Salton Basin to near the present level of the Salton Sea, leaves the basin to the southeastward of Niland, from which place it sends a branch line into the heart of Imperial Valley. The Inter-California Railroad takes a course southerly from Calexico into Lower California and, swinging thence to the eastward, northeastward, and northward, reenters California at Andrade on the west bank of Colorado River. The San Diego & Arizona Railroad, from San Diego across the mountains into the Imperial Valley at El Centro, is nearing completion. The annual value of farm products of the Imperial Valley alone reached $15,000,000 in 1916 and over $30,000,000 in 1918.

South of the boundary, in Lower California, the lands of the irrigated region are owned in large tracts. There has been little or no colonization. Cultivation is mainly by renters. The principal products are cotton and cattle. Alfalfa is grown to a considerable extent. The improved area is part of the region to the west and northward of the present channel of Colorado River extending to the high ground at the eastern base of the Cocopah Mountains. In this portion of the delta alone there are upward of 200,000 acres which can be watered from the Imperial Canal system, and there have already been brought under cultivation more than 100,000 acres (in 1918). The irrigated area in lower California was probably less than 10,000 acres in 1909. It was about 76,000 acres in 1917. It is rapidly increasing.

At the present extent of irrigation the entire flow of lower Colorado River is at times required by the irrigator and diverted. Thus, for example, in the fall of 1915 and for a period of about 10 days in September, 1918, the only water in the Colorado River below the Imperial Canal heading was the leakage through the brush or rock diverting weirs. It is evident, therefore, that as irrigation is further extended in the basin of this river, the natural flow of the stream will not at all times be sufficient to meet the requirements of the irrigators.

THE NAVIGABILITY OF COLORADO RIVER.

Until the Colorado River made its change of alignment in 1909 the navigation of the river by very light-draft boats was possible from the gulf to and beyond Yuma. The river had, however, lost importance as a navigable waterway when the railroads were built which cross the stream at Yuma and at Needles. Navigation at its best was carried on under difficulties. The river flows in a broad bed with a bottom of fine sand. The width of the stream between banks in straight reaches is generally 600 to 900 feet. In bends and where there is much bank cutting the width is occasionally half a mile or more. At low water there was scant depth and at high water the swift current and large amount of drift added to the difficulties of navigation. At present the ascent of the river by boat from the Gulf of California is understood to be not practical at any stage of the river, owing to the fact that there is no continuous main channel through the Volcano Lake region, where the river spreads its water over a broad area. Under the treaty of Guadalupe-Hidalgo, between the United States and Mexico (1848), it was agreed that neither country would permit any works to be constructed on that part of the river which is the common boundary of the two countries which would interfere with the navigability of the river. The later treaty of 1853 canceled this provision, but guaranteed to the United States the free and uninterrupted passage of vessels and citizens over the same stretch of river. The construction of the Laguna Dam, authorized by an act of Congress in 1904 which gave the Secretary of the Interior the right to divert water from the river for the Yuma project, has interposed a barrier to navigation about 12 miles above Yuma and may be accepted as an indication that the United States regards the navigability of the Colorado River as of no importance. The utilization of the river's waters for irrigation far outweighs any possible utilization thereof for navigation. The most recent examination of the Colorado River, with a view to developing and improving navigation was made by Maj. R. R. Raymond, of the Corps of Engineers, United States Army. His report bears date of May 21, 1914, and has been published as House Document No. 1141 of the Sixty-third Congress, second session. Maj. Raymond, in this report, after referring to the fact that the navigability of the Colorado River has been the subject of preliminary examination several times, states that with the information contained in the reports which he enumerates and that found in other records it was not necessary to make an extensive reconnaissance of the river. He visited the river, however, and says:

> Below Yuma the river flows through a delta country which is constantly being built up by the large quantity of silt carried by the river. The channel is unstable and can not be made stable at reasonable cost. At present the principal channel in Mexico passes through Volcano Lake. In addition to the fact that this part of the river lies in a foreign country, it should be noted that there is so little water available in the river below the heading of the Imperial Canal during low stages that navigation throughout the year is impracticable. The amount of water extracted from the river for irrigation will increase rather than decrease.

After referring to the fact that the growth of commerce along the river would imply an increase of the demand for irrigation water, Maj. Raymond concludes that—

> the improvement of the Colorado River for navigation would defeat its own ends and would be a detriment to the adjacent country, except possibly that flood control would be beneficial.

He finds the situation such that he does not even recommend a survey of the river, and says:

> Attention is invited to the conclusion reached by officers who have examined this river heretofore, which agree with my own. The development of the country by irrigation in recent years makes the improvement even less desirable to-day than it was formerly.

OPERATIONS IN MEXICO.

The Imperial Irrigation District, by ownership of corporation stock, controls the Mexican corporation now known as the Compania de Terrenos y Aguas de la Baja California (S. A.), and through the agency of this company maintains and operates the sections of the canals in Lower California which bring Colorado River water into the district. The anomalous situation is thus presented of an irrigation district organized under the laws of California, being dependent upon a Mexican corporation operating canals in foreign territory under foreign laws for its irrigation water, and in large part, too, for its domestic water. Not only this, but the district must make use of the Mexican corporation for protection against the disaster that would result if the Colorado River were allowed to send its flood northward into Salton Basin instead of southward into the Gulf of California.

Through the agency of the Mexican corporation the district is and has been expending large sums on such protective work. A bond issue of $2,500,000 in 1917 included $500,000 for work on levees and the like in Mexico; this has been expended, as has also $500,000 of an earlier district bond issue. Over $700,000 for additions to the protective works in Mexico are to be included in a new bond issue already recommended by the engineer of the district. Messrs. Elwood Mead, D. C. Henny, and Joseph Jacobs, in a report dated March 5, 1917, and addressed to the Secretary of the Interior and the president of the University of California, present an exhibit showing that about $4,925,000, of which $1,000,000 was made available by congressional appropriation, had been expended on protection work in Mexico. This sum includes $2,300,000, the approximated cost of turning the river in 1906 and 1907 from its erratic course inland back into the original channel to the Gulf of California. It does not include the work being done with funds being provided by the bond issue of 1917. The irrigation district can not, when protection works are involved, wait for international action looking to a control of the Colorado River on a proper course to the Gulf of California. Being the only organization so circumstanced that it can construct levees and otherwise afford protection to the lands of Imperial Valley, both in the United States and in Mexico, it finds itself compelled to act and to build whatever works are found to be necessary, though without any legal way of recovering any part of the outlay for flood control thus occasioned from other parties who are benefited. The owners of Mexican lands which are protected, 200,000 to 250,000 acres, on the Imperial Valley slope of the delta cone, of which more than 100,000 acres are irrigated with water from main canals constructed by the Imperial Irrigation District and its predecessors, contribute nothing to the cost of the protection works, except possibly some rights of way. The Coachella Valley and other interests accept protection afforded by the works of the Imperial Irrigation District as a matter of course.

The Imperial Irrigation District, as above explained, is by force of circumstances compelled to direct large operations relating to the construction and maintenance of canals and levees and other protection works in Mexico. This must be done in compliance with Mexican laws. An independent organization, with an independent board of directors, is required, and this organization is expected to carry out the requests of the district. The freest possible intercourse across the boundary is desirable, but can not be or at least has not thus far been obtained. There should be but one centralized management. The district has endeavored to obviate inconvenience as much as possible by having the same persons on both boards of directors. But at its best the arrangement is cumbersome, inconvenient, and inefficient, and results in much waste of energy and money. This is entirely apart from the other more serious interference with the progress of the work, due to delays and added costs which result from the restrictions imposed on passing men, machinery, and materials across the boundary line. Duty must be paid. The regulations of customs officials must be complied with. Approval of plans is required, not alone by the laws of California, but this has to be followed by authorization on the Mexican side. The possibility of a conflict of the two authorities is always present. All this is cited to show the urgency of early relief from a situation which is fast becoming intolerable.

SOME CHANNEL CHARACTERISTICS AND THE RIVER DISCHARGE.

That the river required but slight assistance to make such changes as those of recent years will be understood when it is recalled that the general fall of the ground from Pilot Knob southerly to the Gulf of California is only about 1½ feet per mile, which the river in its meanderings had cut down to an effective fall of about 1 foot per mile. Toward Volcano Lake in a southwesterly direction from the same point the surface gradient is about 2 feet or more per mile, and westward in the general direction in which the Alamo flows it is nearly 3 feet per mile to the vicinity of Calexico, and thence northward into Salton Basin the country falls away 4 to 5 feet per mile. These gradients which apply to ground surface and do not represent the fall of the water surface following the meanderings of the river, will explain why the river can so readily establish a new channel when once an adequate cut or breach has been made in its west or north bank.

While the river was on a course to the Salton Sea, 1905 to 1907, and again since 1909 on its course to Volcano Lake, the energy represented by the water flowing on the heavy gradients on these lines caused the water to cut deep into the ground. This phenomenon was accomplished by a recession of grade upstream, so that at the present time the bottom of the river bed from Hanlon downstream is lower than it had been while the river was on its original course to the gulf. While it is not possible to present conclusions in precise figures as to the amount of this depression of the river channel, it can be stated in general terms that as far upstream as Pilot Knob, near the heading of the Imperial Canal, it amounts to 4 or 5 feet. The resulting lower elevations of the river's low waters make it more difficult to divert water into the Imperial Canal; but the carrying capacity of the river has been somewhat increased by the depression of the river bed. The river temporarily can carry more water in its channel without overtopping its banks than it could carry preceding 1909 while flowing on a direct course to the gulf. The flood menace in the upper delta reaches of the river is therefore less than it would be if the river had not changed its course, but evidence is reported that the river is now beginning to raise its bed again.

The channel of the lower Colorado River in its straight reaches has a width of 600 to 900 feet. In its bends it may spread out to half a mile or more. Its bottom is a fine sand, which under a steady flow of water is packed hard and firm but which yields readily to the shock of waves and swirls.

At its low stages, as already stated, the river has a discharge of 3,000 to 5,000 second-feet. When in flood its discharge may rise to more than 200,000 second-feet.

The following tabular data will give some idea of the amount of water which is carried by Colorado River past Yuma and the amount supplied by the river's principal tributaries:

TABLE 1.—*The discharge of Colorado River.*

[From records of the United States Geological Survey.]

[Annual run-off in acre-feet.]

Year ending Sept. 30—	Green River at Green River, Utah.	Grand River at Moab or Cisco, Utah.	San Juan River near Bluff, Utah.	Colorado River at Yuma, Ariz.
1894–95	4,440,000			
1895–96	4,160,000			
1896–97	5,980,000			
1901–2				[1] 7,110,000
1902–3				11,100,000
1903–4				9,870,000
1904–5				18,900,000
1905–6	6,360,000			19,200,000
1906–7	8,950,000			26,000,000
1907–8	4,290,000			13,600,000
1908–9	8,580,000			26,100,000
1909–10	4,710,000			15,000,000
1910–11	4,160,000			16,200,000
1911–12	6,160,000			19,600,000
1912–13	5,370,000			12,000,000
1913–14	7,080,000			19,900,000
1914–15	3,620,000	5,350,000	[2] 2,700,000	15,800,000
1915–16	5,740,000	7,500,000	3,240,000	21,300,000
1916–17	8,070,000	8,780,000	3,340,000	22,100,000
1917–18				13,000,000

[1] 9 months only, January to September, inclusive.

[2] 11 months (October, 1914, is missing).

THE IMPERIAL VALLEY AND ITS DEVELOPMENT UNDER IRRIGATION.

That in comparatively recent geologic times the Gulf of California extended far to the northwest beyond its present limits is a well-known fact. Its upper end was to the northward of Indio. The detrital matter washed down from the mountains gradually pushed the water back from their bases, and that which was brought from far inland by the Colorado River built a low flat delta ridge entirely across the ancient gulf, cutting off its upper portion from a connection with the ocean. It dried up, and the bed which it occupied is now generally referred to as the Salton Basin. The greater area around and including this basin, which lies between the Coast Range Mountains on the west and the Colorado River range on the east, is known in its northern part as the Coachella Valley and in its southern part as the Imperial Valley. Both the Salton Basin and the Imperial Valley overlap the international boundary, their southernmost portions being in Mexico.

In its natural condition this entire region was an unproductive arid rigion. The annual rainfall here averaged only 2 or 3 inches. There is very rarely enough run-off to reach the bottom of the great depression. This was dry except for the periodical inflow of flood waters from the Colorado River, as in 1840, 1852, 1859, 1862, 1891, and no doubt in other years.

The occasional inflow from Colorado River was more or less concentrated in depressions and channels, of which the most prominent within California was New River, whose head was in the Volcano Lake region, some 20 or 25 miles south of the international boundary line. Much of what is now called Imperial Valley was at one time generally known as the New River country.

The delta ridge already referred to was built up by the river to a height of about 36 to 37 feet above sea level at Volcano Lake and at this height was an effective barrier between the Salton Basin and the Gulf of California. Colorado River, in the process of building up this barrier, would for some centuries discharge inland into the basin and then again for other centuries southward into the gulf. During the long maintenance of an interior lake at the outflow elevation of about 36 feet above sea level a beach was formed which, although no water has been standing at it for more than 400 years, is distinctly traceable. The bed of Salton Basin was naturally smooth surfaced and dipped gradually to a lowest central point some 280 or more feet below sea level.

At the present time about 300 square miles of the bed of the basin are covered with water, the remnant of the flood accumulation in 1905 and 1906 when the entire river for a time discharged inland. This topographic situation on the lower Colorado has long been understood. At an early day in the history of California it gave rise to a scheme for the irrigation of a large area in what is now known as Imperial Valley. Dr. O. M. Wozencraft, as principal promoter, with Ebenezer Hadley, the county surveyor of San Diego county, as his engineer, worked out a project some 60 years ago for the colonization and development of lands in California under irrigation with Colorado River water. Their proposition involved a diversion of water from the river toward the west into the region drained by the Alamo River, which would then carry it, substantially as under the later scheme, to the points in California from which it could be distributed by a canal system.

This project involved a grant of Government land to California amounting to about 3,000,000 acres. It was approved by the Legislature of California, but the necessary bill failed to pass Congress. Subsequently an examination was made under Government direction to determine whether or not it would be feasible to reach the Imperial Valley without following a route through Mexico. This examination was made in 1876 by Lieut. Eric Bergland, Corps of Engineers, United States Army, who acted under the direction of Lieut.

Geo. M. Wheeler. He reported unfavorably upon a canal location entirely in the United States, but again called attention to the natural route across Mexican territory.

Despite this report, which was discouraging to those who desired to have water supplied to the desert in a canal located throughout its entire length on United States territory, the efforts to get water into the Imperial Valley did not cease. But no proposition gave promise of success until Mr. C. R. Rockwood and his associates organized the Colorado River Irrigation Co. in 1892. Surveys were made and works were planned to deliver water from Colorado River in California across the boundary into a short canal in Mexico, which would discharge into the Alamo River, down which it would then flow to a reentry into California. This company, failed however, and was succeeded in 1896 by the California Development Co. At the head of this company, except for two years 1900–1902, was the late Mr. A. H. Heber. Mr. Rockwood remained in charge of engineering and construction. A reorganization of the company in 1905 put the control of its affairs into the hands of the Southern Pacific Co. From 1910 until 1916 the property of the canal company was in the hands of a receiver. In 1914 the Imperial Irrigation District was organized and two years later took over the canal properties, which included all the shares of stock of the Mexican corporation through which the properties in Mexico are managed.

Notice of intention to divert water for the irrigation of lands in the Imperial Valley was given repeatedly from May 16, 1895, to April 25, 1899. The various notices all specified 10,000 second-feet as the amount to be diverted, and the places of posting the notices were at 3,000 feet to 1½ miles north of the international boundary line.

The canal of the California Development Co., as originally constructed, had its head in California at Hanlon's or Hanlon's crossing, about 100 yards north of the international boundary. The canal was cut from the river at an oblique angle, and its flow was controlled by a timber structure. On a falling river, the head of the canal and the headgate were obstructed by silt deposits, and it became difficult to keep the water flowing from the river into the canal. The water shortages due to this cause in 1903 and 1904 and the failure of various remedial measures prompted the application to Mexico for a concession under which a diversion would be allowed on Mexican territory. This concession was granted in 1904, and operating thereunder, the dredger cut was made about 4 miles below the boundary line in Mexico which caused the river, a year later, to turn for a time inland away from its course to the gulf. It is not proposed to describe the Imperial Canal system in detail, but these main facts are here alluded to for a full understanding of the problems of the lower Colorado. The clause in the Mexican concession relating to the use of Imperial

Canal water in Mexico and the one immediately preceding it are as follows:

> The Sociedad de Riego y Terrenos de la Baja California, S. A., is authorized to carry through the canal which it has built in Mexican territory, and through other canals that it may build, if convenient, water to an amount of 284 cubic meters per second from the waters taken from the Colorado River in territory of the United States by the California Development Co. and which waters this company has ceded to the Sociedad de Riego y Terrenos de la Baja California, S. A. It is also authorized to carry to the lands of the United States the water with the exception of that mentioned in the following article.
>
> From the water mentioned in the foregoing article, enough shall be used to irrigate the lands susceptible of irrigation in Lower California with the water carried through the canal or canals, without in any case the amount of water used, exceeding one-half of the volume of water passing through said canals.

The concrete headgate of the Imperial Canal at Hanlon, which was constructed in 1906, has a sill at elevation 100.7 feet above mean sea level (United States Geological Survey datum). This was at that time believed to be low enough to accomplish diversion of the desired amount of water at any stage of the river. The large amount of sand which has annually been carried into the canal and the depression of the water surface in the river below the assumed minimum elevation have combined to make the diversion of an adequate quantity of water at the river's low stages impossible. This is true despite the fact that a few years ago, a 25-foot section of the headgate sill was lowered 5 feet. Imperial Irrigation District has, therefore, found it necessary to construct temporary weirs across the river of rock and brush. Such a weir was constructed in 1910 and annually since 1915.

There is some water obtained for the irrigation of lands in the Imperial Irrigation District and in Mexico from Volcano Lake through the Cerro Prieto Canal. This is only a temporary expedient. The connection of the Cerro Prieto Canal with Volcano Lake was made in 1916. Water has thus been made obtainable from the Volcano Lake region while the river is high. As this water is drawn from an extensive ponded area it is comparatively clear and its use has materially reduced the difficulty with silt in the west-side canal system. The maximum amount of water obtained from this source has exceeded 800 second-feet. This source of supply will be available only so long as the river is allowed to send its flood waters against the Volcano Lake Levee. The time will come when the river is put back upon a direct course to the gulf, and thereupon this source of supply will no longer be available.

The area of the land brought under irrigation from the Imperial Canal system both in California and in Mexico, as already stated, has been growing rapidly. No cultivation is possible in this region without the artificial application of water to the soil; and as the only source of water has been the canal system of the Imperial Irrigation District, this development and general prosperity is to be ascribed to the successful operation of the Imperial Canal. The extension of irrigation in our own as well as in foreign territory by a unified single canal system has been accomplished without international treaty, by the unique method of operation in Mexico through the agency of a Mexican corporation whose stock is owned and whose affairs were directed by the predecessors of the Imperial Irrigation District and are now being directed by this district.

THE YUMA PROJECT.

The Yuma project is a United States Reclamation project located in Arizona and California on both sides of Colorado River. The construction of project works was recommended by a board of engineers on April 8, 1904, and construction was authorized by the Secretary of the Interior on May 10, 1904.

The Laguna Dam at the head of the project canal on Colorado River, about 10 miles northeast of Yuma, was completed in March, 1909. Its cost, including some river bank revetment and the diverting works, has been about $2,100,000. Some water was used on the project lands prior to the completion of the Laguna Dam through ditches which had been acquired from private owners. The main canal of the project is located on the California side of Colorado River from the Laguna Dam down to a point opposite Yuma, and its water is taken thence to the Yuma Valley, on the Arizona side, through a large inverted siphon under the Colorado River at Yuma. The project plan provides for large pumping plants below Yuma on the east main canal for raising water to irrigate about 50,000 acres of mesa land.

Its proposed extent is about 120,000 acres, but there may be future additions. In the Yuma Indian Reservation on the California side of the river there are about 15,000 acres of irrigable land; in the Yuma Valley about 55,000 acres; and on the Yuma mesa about 50,000 acres.

The lands of the project adjacent to Colorado River are protected against overflow by heavy rock-faced levees and ample heavy equipment; also two quarries and a railroad on the entire length of the levees are maintained in order to afford means for protection during flood stages of the river. A drainage system is required and is now under construction.

The population in the project area, including Yuma, is about 12,000. The value of the crop output in 1917 from about 35,000 acres under cultivation was about $3,750,000. In 1918 the cultivated area was about 45,000 acres, and the value of the crops from this area exceeded $5,000,000.

COLORADO RIVER AS INTERNATIONAL BOUNDARY.

Had the character of the lower Colorado River been better known it would never have been made a part of the boundary line between the United States and Mexico. The river is not, as is now well known, in a stable location. Throughout some 20 miles of the river's course where it forms the boundary and now for some 40 miles or more farther downstream, where the river is entirely on Mexican territory, the river, as already stated, has been and now is a menace to large areas of lands and large property interests in the United States and Mexico. If allowed to do what human operations in Mexico have predisposed it to do, it would discharge inland into the Salton Sea and it would be only a question of time before this sea would expand to the full limit of the Salton Basin, with a surface area of some 1,250,000 acres, extending from above Indio in California to about 20 miles south of the international boundary.

Due to the unfortunate location of the boundary line the United States has no jurisdiction over the territory in which the flood menace to Imperial Valley lies. Mexico seems impotent to cope with the situation, or at any rate appears to take no note of the urgency and seriousness of the situation as we are endeavoring to sketch it. In such circumstances the Imperial Valley, or more particularly the Imperial Irrigation District, representing the largest organized interests in the valley, has been constrained to construct and maintain at large cost extensive protective works on foreign territory.

These facts are recited because the usefulness of an all-American or any other canal for the irrigation of lands in the Imperial Valley would soon be in large measure destroyed if adequate protection is not had against the danger from the south which threatens the area already under irrigation. This danger, moreover, will continue to grow so long as the Colorado River is allowed to run wild in the Volcano Lake region. It is evident that the problem of irrigation in the Imperial Valley is interwoven with the other problem of protection against the river at its high stages.

If the United States and Mexico were cooperating on lower Colorado River problems this board would not now find itself embarrassed by being denied the opportunity to survey and propose other possible high-line canal routes than such as are wholly on United States territory. To the westward of Pilot Knob the mesa slopes to the southward and southwestward. It breaks off in a comparatively steep slope a few miles to the southward of the international boundary. It is known that a canal without material sacrifice in water-surface elevation could be placed on lower ground than north of boundary by swinging the canal line across the boundary. It is not known definitely what the material advantage of such a location would be, though old surveys and a partial reconnoissance indicate that a reduction in excavation to the extent of about 10,000,000 cubic yards might be expected.

WATER CONSERVATION BY STORAGE.

Whenever the river drops to a low stage early in the season, as was the case, for example, in 1915 and in 1918, the demand of the irrigator upon the lower river will be in excess of the water supply. This situation will become more pronounced when all the land in Imperial Irrigation District and in the Yuma project susceptible of cultivation shall have been brought under irrigation.

The irrigated lands and the lands susceptible of irrigation with water from the lower Colorado River are therefore directly concerned with the conservation of the river's flow, and particularly with the regulation thereof by storage. The construction of storage reservoirs should go hand in hand with the building of any irrigation system that will add so large a body of arid land to the irrigable area as would the construction of a full-capacity all-American canal.

When, therefore, project features are outlined for the full utilization of such a canal, or its equivalent, there should be assurance that some water will be obtainable for it from storage. It is assumed that within the time that such a canal could be built the United States Government will have made suitable provision for storage works that will be of general benefit. It may also be assumed that water from storage will be supplied at a charge which will fairly compensate the United States and will return to it the proper allotment of original investment within a period of 40 to 50 years and that there will be no immediate demand upon the irrigation interests benefited for any part of the first cost of reservoir construction. On these assumptions the new area to be served with water from the all-American canal will not be burdened with the necessity of providing funds to meet the first cost of storage works, and all complications that might otherwise result from negotiations with up-river interests will be avoided.

Some idea of the large storage possibilities on the Colorado River and its tributaries is obtainable from the following table, in which the most notable reservoir sites in the drainage basin of the river (not already in use) are enumerated. This information is only tentative. Further investigations and studies will be essential to determine feasibility and economic heights of dams.

TABLE 2.—*Some of the important reservoir sites in the drainage basin of Colorado River which are under investigation by the United States Reclamation Service.*

Designation.	River.	Depth of storage at dam (feet).	Capacity (acre-feet).
Juniper	Yampa	200	1,550,000
Browns Park	Green	200	2,520,000
Flaming Gorge	.....do	225	3,500,000
Ouray	.....do	170	10,000,000
Kremmling	Grand	230	2,200,000
Dewey	.....do	215	2,270,000
Junction	Green-Grand	270	8,600,000
Bedrock	Dolores	210	800,000
Animas	Animas	110	440,000
Bluff	San Juan	206 264	1,350,000 2,600,000
Sentinel	Gila	130	2,219,000
Rangely	White	170	400,000

THE SILT PROBLEM.

On the subject of silt carried by Colorado River much information has already been collected. The silt studies which have been made by the United States Reclamation Service at Yuma since 1909 and earlier studies by Prof. R. H. Forbes, of the Agricultural Experiment Station of Arizona, have led to the following general conclusions on this subject:

The water of Colorado River ordinarily carries the least percentage (by weight) of silt in suspension during the months June to November.

The water of Colorado River ordinarily carries the highest percentage of silt in suspension from January to March, and this percentage is about three to four times as great as when the river is at its highest summer stage and as in the fall when the river is at a low stage.

The percentage of material in suspension in the water of Colorado River is ordinarily at a maximum when the river has a flow of about 30,000 to 40,000 cubic feet per second and is at a minimum at the low and at the high stages of the river.

The percentage of material in suspension increases with depth below the water surface; in other words, there is more material in suspension near the bottom of the river than near the water surface.

The annual average load carried in suspension is about 0.85 per cent by weight, and the range throughout the year is from about 0.20 per cent at low water and 0.30 per cent at high water to an ordinary maximum of about 1.45 per cent and to an occasional maximum at certain intermediate stages of about 4 per cent.

There are numerous wide departures from these general conditions.

It is estimated from these figures and the mean annual flow of Colorado River at Yuma that the river's annual load of silt carried in suspension is about 196,700,000 tons, which at 100 pounds to the cubic foot, represents about 90,000 acre-feet of compactly deposited dry material.

This does not include the river's bottom or bed load of sand, concerning which little is known other than that the river at its high stages occasionally makes rapid changes in depth and that the bottom, being loose sand, yields readily to the erosive force of the water.

The studies which have been made in the Imperial Canal indicate that at an annual discharge of about 2,000,000 acre-feet the average bed load of the canal has been at least 190,000 cubic yards per month, or about 2,280,000 cubic yards per year. It will be safe and conservative to assume that the river has a bed load at least as many times greater than this as its annual flow is greater. Accepting the records of the United States Geological Survey, the river's annual discharge may be placed at about 17,000,000 acre-feet, or 8.5 times the amount diverted into Imperial Canal. The bed load of the river may therefore be estimated at not less than 8.5 times 2,280,000 cubic yards, or about 19,500,000 cubic yards, or 12,000 acre-feet.

The combined load, in suspension and pushed along the bottom, is therefore equivalent to an average annual deposit of at least 102,000 acre-feet, or enough material to cover 158 square miles 1 foot deep.

In making this estimate it has been assumed that the average weight of 1 cubic foot of dry deposit is 100 pounds. This is based on recent careful determinations of the amount of material in a cubic foot of deposit taken from the bed of Imperial Canal. It is quite possible that this assumption is somewhat in excess of the average weight of the top layer of ground in the delta, but is likely to represent fairly the average weight when the great bulk of the river's deposits, including what lies below the surface layer of soil is considered.

The all-American canal project is for the irrigation of an area of such large extent that when the lands commanded by it, together with those of the Yuma project, are all under cultivation the entire natural flow of the river would be diverted at Laguna Dam for use on both sides of the river during an average of at least one month per year and in some years, as in 1902, 1903, 1904, 1910, 1915, and 1918, from two to six months. At such times, until conditions are modified by storage, water would not be available for desilting operations without a reduction of the diversions to the detriment of the irrigators; but desilting is essential in order that as little as possible of the river's bed load of sand may get into the canal systems and that the suspended load in the waters of the canals be kept at a minimum.

During the months when the irrigation demand is equal to or exceeds the quantity of water in the river at the Laguna Dam there is then urgent need for water from a stored supply to make up the natural deficiency with an ample allowance for sluicing purposes. It is believed that the desilting operation can be carried on successfully at the Laguna Dam without sacrificing more than 5 per cent of what would otherwise be the continuous flow of the canals.

The following table presents in condensed form the results of the studies made at Yuma from 1909 to 1916 of the quantity of silt carried in suspension by the water of Colorado River.

TABLE 3.—*Silt contents, Colorado River at Yuma, 1909 to 1918.*

[Information furnished by the United States Reclamation Service. Based on semiweekly determinations by weight.]

Period.	Average monthly discharge at Yuma (acre-feet).	Percentage of silt by weight.	Volume of silt at 100 pounds per cubic foot (acre-feet).
January, 1911–1918	717,440	1.70	7,620
February, 1911–1918	753,945	1.39	6,560
March, 1911–1918	1,016,158	1.10	6,860
April, 1910–1918	1,478,195	.91	8,380
May, 1909–1918	2,887,910	.82	14,800
June, 1909–1918	4,411,205	.57	15,800
July, 1909–1918	2,881,308	.76	13,800
August, 1909–1918	1,207,054	1.12	8,430
September, 1909–1918	743,196	.97	4,500
October, 1909 and 1911–1918	865,093	1.40	7,570
November, 1910–1918	548,418	.59	2,040
December, 1910–1918	465,064	.33	970
Total and average	....	.85	97,330

The flow at Yuma and silt contents are affected by the sluicing operations at the Laguna Dam. The influence of sluicing is probably negligible at the river's high stages, March to August. If taken into account for the remainder of the year the silt contents would probably appear slightly less than shown in this table. The mean diversion of water at the Laguna Dam throughout the year has not exceeded 1,000 second-feet. There was practically no diversion preceding 1910.

THE FLOOD MENACE.

The contract between the Secretary of the Interior and the Imperial Irrigation District, under which this board has been appointed, is specific and definite in its requirement that an all-American canal route be surveyed and examined. No alternative has been left open. The surveys and investigations which have been made relate, therefore, to a canal, located throughout, upon American territory. Our investigations could not be broadened out to a full consideration of the wisest and best treatment of the irrigation problem of the lower Colorado River in its broadest aspect. This is to be regretted, because the lower river presents problems of unique perplexity. The river is not alone the sole dependency for irrigation water for large areas in both the United States and Mexico, but its floods have become a menance to property interests in both countries by reason of the fact that these floods threaten extensive areas with permanent destruction. In the case of most regions which are subject to overflow from rivers the occasional flood is held in check by levees, which if they break cause more or less inundation with inconvenience and loss of property and perhaps of lives, but the water recedes in the course of a week or a month as the case may be.

On the lower Colorado, however, the situation is entirely different. The river from the head of its delta to the Volcano Lake region is from 300 to 400 feet higher than the lowest portions of the Imperial Valley. The river in fact flows on the southeasterly rim of this valley—if a very broad flat delta ridge may be regarded as delimiting the valley in this direction—at an elevation above sea level from low to high water in round numbers of 100 to 120 feet near Pilot Knob at the head of the delta and at an elevation of 30 to over 40 feet in the Volcano Lake region. These elevations of the river are to be compared with sea level as the general elevation of the ground near Calexico on the boundary between the United States and Mexico, 50 feet below sea level at El Centro, 110 feet below sea level at Brawley, and over 280 feet below sea level at the deepest points of the bed of Salton Sea.

On the present route of the lower Colorado, practically along the top of the delta ridge to Volcano Lake, any overtopping of the river's west and north or right bank, if not restrained by artificial barriers, would send water inland down a slope into the Salton Basin. This basin to the southernmost portion of which the name Imperial Valley has been given, has a surface extent of about 2,000 square miles. Being a depressed basin, there can be no return flow therefrom to the river until the basin is full. A large part of the north central portion of the river delta—that is to say, land near and to the northward of the present Abejas section of the river—has for some years past escaped submersion. The result has been that vegetation has died out to a large extent, thus leaving this region more exposed to erosion at flood if barriers are broken than was the case under natural conditions. Any flood waters of the river which go over bank toward the north must, therefore, at all costs be returned to the river and not allowed to flow down the northern slope of the delta cone. This is being done by the maintenance of levees judiciously placed on high ground, frequently some miles distant from the present river channel.

From the head of the river delta at Pilot Knob to its outfall into the Gulf of California the right or west bank of Colorado River is in Mexico. Consequently all of the levee work for the protection of the

Imperial Valley has been done in Mexico. This levee work, although upon foreign territory, has been done without contribution by Mexican interests. Not only were several millions of dollars expended in 1906 and 1907 in turning the river from its suddenly established northerly course back into the gulf; but since then a million dollars, contributed by the United States, were expended on levee work in Mexico and in addition thereto, the Imperial Irrigation District and its predecessors have spent more than another million in levee maintenance, levee extention, and betterments, all giving protection to Imperial Valley and other lands, and all necessarily in foreign territory.

Without attempting to give a full history of the efforts which were made to keep the head of the Imperial Canal from being choked with river silt and of the many other difficulties relating to maintenance of flow in the canal and to protection against flood which were successfully overcome, the following facts bearing upon the flood menace may be briefly recalled:

The original canal heading or intake from the Colorado River was in California, a few hundred yards north of the international boundary line. Owing to trouble with silt it could not be kept open at sufficient capacity to meet the growing demands of the irrigators, and when in 1904 the concession was obtained from Mexico to make a diversion on Mexican territory another intake channel was constructed just south of and paralleling the boundary ine, delivering into the canal, which was there only a few hundred feet from the river bank. As this did not sufficiently improve the situation, another cut was made about 4 miles farther downstream, at the so-called lower Mexican heading. In 1905 the river scoured out this cut to river dimensions and in November of that year completely changed its course, sending a flood of water over the broad flat areas of Imperial Valley. In December, 1906, the river was turned back into its old channel by the construction of the so-called Hind Dam, but broke out again a few weeks later. It was turned back a second time in February, 1907, by the construction of the Clarke Dam, which is practically a southern extension of the Hind Dam. In 1909, about 20 miles by river below the California boundary line, the river again left its old channel and cut a new channel westerly, dropping its waters into a delta channel known as the Abejas or Bee River. It abandoned its old bed below this point. On the new route it flows westerly into the Volcano Lake region. Its waters there inundate a broad extent of country which is being raised by silt deposit and in which the copious annual watering has stimulated the growth of willows, brush, and plant growth generally. To the northward the spread of the waters is checked by the Volcano Lake levee, now an embankment about 13 feet high, against which in 1917 for 10 miles or more water stood 7 to 8 feet deep. To the southward the water finds its escape from the Volcano Lake region through various channels and over low areas, dropping finally into the Hardy Colorado and its feeders and thus reaching the Gulf.

The Imperial Irrigation District is under the necessity of adding constantly and at an ever-increasing rate to the extent and magnitude of the defenses which must be maintained to keep the river from turning to the north. The river has in the last few years deposited so much silt toward the west and south in the Volcano Lake region, over which its water flows, that the obstruction of the higher ground thus formed, together with that offered by the rank vegetation of the southerly delta lands which have been periodically under water, has caused the flood menace in this region to increase from year to year. Based on the information at hand since 1914 it appears that the rise of the flood plane now averages about 1 foot per year. Before the river changed its course in 1909 the annual high-water stage in Volcano Lake was about 37.6 feet. In 1917 it rose to about elevation 44.5 above mean sea level (United States Geological Survey datum).

The situation as described is serious, and the menace is growing. The control of the lower river is an international problem. The area to be protected by putting the river upon a direct course to the gulf lies in both Mexico and the United States. No time is to be lost in dealing with the problem, which can not be adequately handled by the Imperial Irrigation district.

The construction of an all-American canal, while it may relieve the irrigated areas in California from compliance with the conditions named in the Mexican concession, will not solve this other problem, which is also of vital importance to Imperial Valley.

Should an all-American canal be constructed and the carrying of irrigation water through Mexico cease, there will undoubtedly be some provision thereupon made by Mexico to maintain the productiveness of the Lower California lands by a system of irrigation canals heading at the river upon Mexican territory. New works then established may and most likely would introduce new complications and would create a new menace. All such works should be under more or less supervision and control from our side of the line because their failure would menace property interests in the United States which are, for the time being, far in excess of those in Mexico and will always be of great magnitude. This board, therefore, suggests an arrangement with Mexico which is fully explained at the end of this report.

At the river's high stages there will always be an abundance of water. And, when the flood season has passed, those who have not established their claims to an adequate part of the season's diminishing natural flow should be supplied with water from storage. There is no reason why, in such circumstances, under a suitable agreement between the United States and Mexico, this should not apply beyond the United States boundary, so that Mexico, too, may benefit by the use of stored waters whenever an adequate amount of water shall have been provided by the construction of large storage reservoirs in the United States. There is all the more reason for such an arrangement, due to the effect which storage on a large scale would have in reducing the peak of the flood discharge on the lower river. Any reduction of the flood menace thus secured will be of direct benefit to Mexico as well as to the United States.

The levee system which prevents the floods of the Colorado River from taking a northerly course and upon which Imperial Valley is dependent for protection against the menace of destruction, as above stated, is briefly described as follows:

1. The California Development Co. levee, the so-called C. D. levee, was built in 1906 and 1907 by the California Development Co. It extends from Hanlon's just north of the international boundary, southerly along the right bank of the Colorado River a distance of 7 miles and thence southwesterly bearing away from the river an additional distance of some 8 miles, being thence continued under the name of the Saiz levee to a point some 7 or 8 miles northeasterly from the area originally occupied by Volcano Lake.

2. The Volcano Lake levee, on which the first work was done in 1908, and which has been raised from time to time and strengthened and extended. This levee extends from the base of Cerro Prieto easterly for 6 or 7 miles, across the bad lands at the north of Volcano Lake, and thence northeasterly to a connection with the embankment of the Inter-California Railroad. Its total length is about 16 miles.

3. The Ockerson levee, constructed in 1911 for the primary purpose of returning the flow of the Colorado River back into its original course to the Gulf of California. The river had in 1909 abandoned its channel about 2 miles below the Arizona boundary line and taken a westerly course into the Volcano Lake region along the general route of the Abejas high-water channel which it enlarged to river dimensions. This levee was breached at the head of the Abejas and also at several other places soon after its construction. It has not been repaired. The river still flows into the Volcano Lake region as elsewhere explained.

In 1906 and 1907 the Colorado River was twice turned from an inland course at points about 4 miles south of Pilot Knob by the construction of rock-fill barriers, which now appear as parts of the C. D. or river levee.

The cost of all the above protection work has been large, probably in excess of $5,000,000.

Within the last year the Volcano Lake levee has been raised 3 feet, at the expense of Imperial Irrigation District, and portions of the Saiz levee have been raised 4 feet. More work is to be done in the near future on these levees, because the menace from the south is growing.

DRIFT.

The amount of drift carried by the Colorado River is very large. It is of all kinds. Large logs, 20 to 40 feet and longer, are numerous. The caving banks supply brush and litter of all kinds and also many cottonwood and willow trees which, being green, float nearly or completely submerged. The drift ordinarily runs near the middle of the stream in the river's straight reaches but close inshore along concave banks. Some is sure to find its way into any outlet from the river into which there is considerable flow of water.

At the Laguna Dam some of the larger type of drift can be seen lodged above the dam and here and there hanging to the crest of the structure. By far the largest portion of the drift shows the effect of having been buffeted about and of having been long submerged. Much has been several seasons in traveling from its place of origin to the lower river.

This drift has thus far given no trouble at the Yuma Canal diversion works. Only a negligible amount follows the water into the desilting channel. The little that gets to the head gates is readily removed when the sluice gates are opened for the usual sluicing operations.

When the Yuma Canal is enlarged there will be more drift at the head gates. It may then be a more difficult problem to dispose of it. Booms may be required to deflect the drift from the entrance of the desilting channel.

THE DRIFTING SAND.

This board has found no practical way of determining how much sand will blow into an open canal on the 10-mile stretch in which the location of the all-American canal is through a region of drifting sand. The sand has been piled by the wind in dunes with crests at some points 100 to 200 feet in height above the general surface of the mesa over which the sand is traveling. These dunes, while much broken, are yet more or less connected in ridges at right angles to the longitudinal axis of the sand-hill area. Between these ridges are depressed areas—the limit of the depression being the surface of the mesa of which areas of various size are here and there exposed between the drifting dunes. The mesa itself is built up of detrital sand, but a sand of quite different texture from that found in the sand hills. The sand of the mesa contains a large proportion of coarse sand grains and fine gravel with a little coarser material up to small cobble size, and just enough of very fine material to be slightly cohesive. The wind has apparently whipped out of its surface much of the fine material which is now adrift in the dunes.

The prevailing wind to which the dunes owe their shape and their grouping is from northwest to southeast. When a strong wind is blowing there is a steady stream of sand over the crest of each sand wave and over the tops of the dunes. These dunes are more or less crescent shaped, with flat-sloping, gently rounded backs to the windward, i. e., toward the northwest, and steep slopes generally about 1.75 to 2 feet horizontal to 1 vertical to the leeward or southeast. The momentary condition is subject to considerable variation, depending upon the direction of the wind and the amount of moisture in the sand. Some shrubs and plants that were found growing on the backs of the dunes were deeply rooted, having pushed their growth upward as layer upon layer of sand was piled on by the wind. Their persistence under adverse conditions indicates, however, that the change in surface elevation is probably slow.

Several years ago a plank road was built through these sand hills. Every storm that blew piled some sand on this road. Some difficulty was experienced in keeping it open. And yet, the amount of sand which the wind deposited on this road was relatively small. The attention of one to two men with scraper outfits sufficed to keep the road passable except for short periods during severe wind storms several days in duration. It would signify but little if the amount of sand removed from the road should fall into a large canal. Unfortunately, however, the deposited sand on any such area as a road surface does not give any dependable clue to the sand which would be trapped by a canal in the same location. Some sand is blown across the road in both directions which does not lodge there. A canal across the sand hills would have a water surface some 30 to 50 feet below the surface of the mesa, and if no precautionary measures are taken the sand blown across the top edge of either bank would fall into the water and would lodge within the canal as an obstacle to be artificially removed.

In recommending a large open canal through the sand hills this board recognizes that the sand may prove troublesome. When it does a remedy must be applied. The following is suggested as one that certainly would be successful. One or more suction dredges can be kept at work in the canal making delivery of the excavated material into basins between the sand hills and covering the sand-hill slopes to such extent that these slopes will become fixed. Furthermore, pumped water can be used for the irrigation of the sand-hill slopes until they are so covered with vegetation that for half a mile or more on each side of the canal the drifting sand will be checked.

In view of such possibilities, the cost estimate which we submit is based on the construction of an open cut with comparatively flat slopes and a wide berm. Some protection will also be secured by a proper disposal of the excavated material with which some of the blow sand can be blanketed.

In the eastern portion of the sand-hill area the drifting sand is of a finer texture than in the westerly portion. It is noticeable that in the eastern two-thirds, approximately, the dunes are in motion from base to crest and that the sand of which they are composed is uniformly fine. It has a very pale, slightly reddish tinge. There is very little vegetation. A sample taken at random, but fairly representative, shows the composition noted below in the table.

On the western one-third of the area darker spots are noticeable on the surface of the dunes. There is a little more vegetation, the vegetation appears more permanent, and the crests are more broadly rounded. Probably more than one-half of the area is of this darker color, which on observation is found to be due to a coarser, grayer sand. This coarser material does not run with the wind as freely as the finer material, and it is noticeable that secondary dunes of an intermediate grade of sand of comparatively small height are traveling over the more permanent gray sand. The last or most westerly ridge of sand to be cut by the canal is of the coarser texture and there is, therefore, less to be feared here from sand drifts than farther east.

The following comparisons will give some idea of the difference in texture of the sands as they appear near the surface:

TABLE 4.—*Sand from the sand hills.*

Fineness—passing screen No.—	Easterly portion, fine drifting sand.	Westerly portion, gray drifting sand.	Westernmost ridge.	
			Gray drifting sand 1 foot below surface.	Surface sample of drifting sand.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
200	1.5	3.5	2.1	2.0
100	41.5	18.0	27.0	30.0
50	99.0	39.5	71.0	63.0
40	99.8	63.0	89.0	80.0
30	....	91.0	99.0	91.0
20	....	98.0	....	95.0
10	All.	All.	All.	All.

THE CANAL CAPACITY.

In determining that the all-American canal should be planned for a capacity of 9,000 second-feet, consideration was given to the following facts:

On the 586,000 acres within Imperial Irrigation District it is estimated by those supposed to be best informed that 515,000 acres will ultimately be under cultivation and therefore irrigated. The west-side canal can be extended and constructed on lighter grade whereby some 40,000 acres more west-side land, not now within the district, can be added to the irrigated area.

On the east-side mesa there are about 200,000 acres of land of which it is estimated it is feasible to irrigate 140,000 by gravity flow.

Northward from what is generally known as the east-side mesa on the eastern slope of the valley and extending to Coachella Valley there are about 115,000 acres of land that will be commanded by an extension of the mesa canal, of which probably 75,000 acres net should be considered as being suitable for irrigation.

Still further north lies the Coachella Valley where irrigation might be extended to possibly more than an additional 75,000 acres. Of pumpage area there are about 30,000 acres on the east-side and about 25,000 acres on the west-side mesa.

Without at the present time including lands so remote as those to the westward of the northerly end of Salton Sea, the net irrigable areas to be considered aggregate 900,000 acres. It is to be understood, however, that whenever it shall become apparent that water is available for a larger area and the demand for extension is made, the canal can be enlarged by dredging and the irrigated area can be extended beyond the limit named as the basis for the project.

Based on the experience in the Imperial Valley and in the Yuma project it has been found that a delivery of about 3.33 acre-feet of water per acre per year and a diversion from the river of about 4.44 acre-feet for each acre of the irrigated area should adequately meet the requirements of general farming as the same has been practiced in these regions. It is known that the losses of water from the Imperial Canal in its course through Mexico in a distance of about 50 miles are from 15 to 20 per cent of the amount diverted from the river, or in round numbers, according to the canal stage, about 7.5 to 20 second-feet per mile of canal. It is also known that the losses in the secondary mains in Imperial Valley are light, probably not much in excess of 10 per cent.

The all-American canal will be subject to ordinary canal losses from the Laguna Dam until it gets beyond Pilot Knob. Thence westerly for nearly 20 miles the water surface of the canal will be deep in the ground. The canal bottom in this stretch will be at an average depth of about 50 feet below the surface of the mesa. The canal may for a time, at the beginning of operation, lose water here as it would if in shallow excavation, but presently the lower layers of the mesa formation will be filled with water and the canal losses will be restricted to what these layers can carry away. This amount will probably be small—probably not one-half of the amount which is lost by the Imperial Canal per unit of length. Allowing, however, an equal loss in amount per mile, or from 7½ to 20 second-feet for the all-American canal to the point where delivery into the head of a mesa canal will be made, the loss would be only about 6½ to 7½ per cent.

At the headworks there will be waste due to the desilting operation. This may, as elsewhere stated, amount to about 5 per cent. It is believed, under these circumstances, that an allowance of about 15 per cent for all losses down to where the canal will deliver into the east-side mesa canal, will be adequate and that the figures above noted relating to the per acre requirements, based on experience, which allow for 33⅓ per cent more water diverted than is applied to the land, may be accepted as a safe guide in determining the amount of water required to supply the needs of 900,000 acres of cultivated lands.

It is, of course, quite possible that after some years of operation, when the canal beds have been rendered less pervious by deposits of mud and silt, the more sanguine estimate of canal loss as noted in Mr. Preston's report will be realized.

The demand for water by months will be about as shown in the following table, which is based on the assumption, not strictly true, that the canal loss will be proportional to the amount diverted. The percentage of loss will in fact be somewhat less when the canal is flowing full than when at a low stage, because the loss is more nearly proportional to canal water-surface area in the canal than to volume of flow, and the water-surface area increases at a less rate than does the volume of flow.

TABLE NO. 5.—*The irrigation demand, by months.*

Month.	Per cent of annual requirement.	Average delivery to the irrigated land (depth in feet).	Average diversion for the irrigated land (depth in feet).
January	3.0	0.10	0.13
February	5.0	.17	.23
March	9.0	.30	.40
April	10.0	.33	.44
May	12.0	.40	.53
June	13.5	.45	.60
July	13.5	.45	.60
August	11.5	.38	.51
September	9.5	.32	.42
October	7.0	.23	.31
November	4.0	.13	.18
December	2.0	.07	.09
Total	100.0	3.33	4.44

The maximum demand for irrigation water will determine the canal capacity. The maximum demand is expected in June and July. In these months the diversion from the river should be in such amount that if all the water were delivered without loss in transit it would cover the entire cultivated area in each of these months to a depth of 0.60 foot or 7.2 inches. The duty of each second-foot of water diverted would, if expressed otherwise, be 100 acres. The canal to supply the desired amount of water to a cultivated area of 900,000 acres in Imperial Valley should have a capacity of 9,000 second-feet.

For the Yuma project, with some allowance for expansion beyond the limits generally indicated, a maximum diversion of 1,600 second-feet has been assumed. This is the amount for which the Reclamation Service desires that capacity be provided and for which the original project canal was constructed.

The required canal capacity, therefore, of 10,600 second-feet results, from the Laguna Dam down to the point at the siphon drop where the Yuma water is to be delivered to a separate canal and 9,000 second-feet for the all-American canal below this point to the upper mesa canal heading where the main supply for the east mesa would be taken off.

The board, upon request of the Directors of Imperial Irrigation District, submits as an alternative the estimated cost of constructing the canal at first at a capacity of only 6,000 second-feet to meet the immediate needs of the district. The structures for this alternative have, however, been planned at full capacity to meet early future requirements. The power plants would be the same as for a full-capacity canal.

METHODS OF CONSTRUCTION AND UNIT COSTS.

The work of excavating the canal should be done to the maximum extent possible by machinery. The climatic conditions are not favorable for securing good results with ordinary labor. For work of the magnitude of an all-American canal, particularly for the deep uniform excavation westerly from Pilot Knob, special methods or types of machinery and appliances may be designed to do the work expeditiously and economically. It is possible that such methods or machinery can be perfected and brought into successful operating condition, and that thereby the cost of the work can be somewhat reduced. Nevertheless, it would not be safe to assume other methods of construction as the basis for a cost estimate than such as have been standardized by experience.

It would be useless to speculate as to what the operating and plant costs of special types of such machinery would be when, perhaps after considerable experimentation, they have been brought into a condition to operate successfully. This board believes that it would be unwise to permit any experimentation which does not at the outset give almost certain promise of success, and it has, therefore, adopted unit costs based on methods of work which experience has standardized and which will give assurance of successful accomplishment within a time limit that can be predicted with some certainty.

It is known that practically all of the work can be done with such standard equipment as drag-line excavators and steam shovels and that such work, under payment for electric energy or the generation of power at the drops or with oil as fuel, should be done at a cost of about 20 to 30 cents per cubic yard when no powder is required to loosen the material, and 75 cents per cubic yard for rock.

Wherever the conditions are such that the excavated material must be transported for a considerable distance lengthwise, steam shovels are well adapted for the work. They will load upon cars, and trackage will have to be provided to send the excavated material to selected dumps or to some place where its deposit will be of some use.

For the rock cuts at and adjacent to Laguna Dam, steam shovels with the addition of a clamshell or orange-peel excavator and a hydraulic dredge for the excavation of the desilting basin are contemplated. The material from the rock cuts will be hauled for use in the training jetty of the settling basin and to riprap the levee, which affords protection to the upper end of the main canal. Some of this material may be placed in the reservation levee of the Yuma project, but the haulage costs for this work would not be charged to the all-American canal.

For the enlargement of the 10 miles of the Yuma project main canal to siphon drop large size drag-line excavators are contemplated. These will handle all the material with the exception of a few short stretches where the main canal hugs the base of the mesa bluffs. In these stretches a medium-sized steam shovel will be used.

From siphon drop to Araz practically all the work is suited for drag-line excavators, and from Araz to Pilot Knob for steam shovels.

At Pilot Knob, too, practically all the excavation will be made with steam shovels. Space for spoil along the line of the canal, which will be but a few hundred feet from the international boundary, is limited. The excavated material must nearly all be transported for a considerable distance lengthwise of the canal. It is proposed to have the steam-shovel track system connected with the track on the "River" levee and to extend this track the full length of the Saiz levee and also to put a track on the Ockerson levee, connecting with this line and extending to the head of the Bee River. It will thereby be made possible, at the cost of some extra haul, which is small, to send the material from the canal to the "River," Saiz, and Volcano Lake levees which need raising and strengthening. A small proportion of the steam-shovel excavation on the south slope and a large proportion of that on the east slope of Pilot Knob will be rock, suitable for river bank and levee facing. When once loaded upon cars this material should be placed, so far as it is economically feasible, where it will be useful in affording protection against the flood menace.

In the board's estimates of cost no addition has been made for long haul when material is thus disposed of, it being assumed that some provision will be made to meet this small additional cost out of special funds that will have to be raised from time to time for protective work.

Excavation of the sand-hill stretch of canal by electrically operated shovels is contemplated. Power for the shovels will be furnished from the power station at Pilot Knob. Some grading and construction of track and the establishment of permanent camps would be done before this power is available, while the power house is being constructed and the connection with the Laguna Dam is being made. Active excavation with a full plant would begin about 18 months after the work on the upper sections of the all-American canal begins. Each steam shovel would be operated so as to give a net output of two shifts or an average output of at least 4,000 cubic yards per day, or 120,000 cubic yards per month. Twelve shovels in operation would excavate about 1,440,000 cubic yards per month. As their full task would be 50,000,000 cubic yards, they should complete the canal prism from the easterly edge of the mesa at Pilot Knob to the mesa canal heading in about three years.

The excavated material under such method of work would be sent to spoil dumps so located as to be of maximum benefit in checking the drifting sand. With a fair allowance for profit this work can be done at about 30 cents per cubic yard, and this price has, therefore, been adopted as the basis of the cost estimate for this part of the work.

Westward to the mesa power station No. 2 the canal will no longer be deep in the ground and excavation can readily be handled with drag-line excavators.

Westward from the deep cut below power station No. 2 grading outfits are contemplated, and some means must be provided to compact embankments which sustain a high water pressure.

Based on such considerations as above, the unit prices which were used to form the basis of the cost estimate will be found noted in Mr. Preston's report.

Work should first be concentrated on the stretch from Laguna Dam to Pilot Knob; this will take about 18 months from the time that definite instructions for its construction are issued. During its construction the work at the Pilot Knob power station should be in progress. More than a year should be allowed for the preparation of the site for this station and the acquisition and placing of the necessary machinery. It will probably be two years before the power station will be in full operating condition. During this time the preparation for the excavation on a large scale of the canal across the mesa would be made so that when the power from the Pilot Knob station is available no time would be lost in getting the excavation machinery to work at full capacity. By providing an adequate excavating outfit for the canal from Laguna Dam to Pilot Knob and rushing this work, the plant can subsequently be used on the canal westward from Pilot Knob, where three or possibly four years must be allowed for completion.

In order to classify the material as to its character and to make the cost estimates more dependable, information was obtained from the United States Reclamation Service relating to the work from the Laguna Dam to the siphon drop. Between the siphon drop and Pilot Knob the character of the hills was ascertained by inspection, particularly at the points where railroad cuts and deep washes exposed the stratification to view. At Pilot Knob a number of pits were put down and holes bored or drilled in the bottom thereof and westerly from Pilot Knob, on the mesa, at points about a mile apart, pits were sunk and borings were made, which tended to confirm the conclusion that on this part of the work there would be no solid rock and only here and there a layer of slightly cemented gravel.

It may be desirable before the work advances to the stage of calling for bids to make some additional borings and excavation on the slopes of Pilot Knob. The board feels safe, however, in accepting the indicated results of these studies already made and knows that there can not be any increase in the amount of rock excavation which would materially affect its conclusions as to the estimated aggregate cost of the whole work.

THE CANAL HEADWORKS AT LAGUNA DAM.

The headworks of the Yuma project canal are to be so modified that the diversion into a common canal will be adequate to supply the irrigation demand of both this project and the Imperial Valley. At the point of diversion on the Colorado River, about 10 miles northeasterly from Yuma, the elevation of the water surface in the river is brought under control by the Laguna Dam. This is a broad, low structure of the weir type, which extends from solid rock on one side of the valley of the Colorado 4,750 feet to solid rock on the other side. The crest of the structure is at a uniform height (elevation 151 feet). At maximum flood stage the depth of water on the crest of the dam is 5.5 feet. This dam raises the water surface of the river about 10 feet at the river's low stage. At high water the fall of the water surface at the structure—that is, the fall from water above the dam to water below the dam—is only about 5 feet. The shape of the crest of the dam is such that some of the large drift carried by the river is caught by the dam at certain stages of the water and hangs there until the water of a higher stage pushes it over.

To some extent checking of drift in this way could be prevented by modifying the shape of the crest. As this is desirable and as there would be material advantage to both the Yuma project and the all-American canal project in holding the water above the Laguna Dam at low stages somewhat higher than heretofore, the board suggests that the crest of the dam be raised 2 feet and rounded, with a short approach from upstream on a gentle slope, so as to offer the least possible obstruction to drift. The advantage of thus raising the crest of Laguna Dam is represented by the saving of about 1,000,000 cubic yards of excavation for each foot that the grade line of the all-American canal is raised.

The board realizes that due to the great length of the Laguna Dam and the broad expanse of the submerged area above the dam there will be a deposit of material to and above the full height of the structure over some areas, and a growth of willows and brush is to be expected, which may so encroach upon the structure that the dam can not function uniformly from end to end. There will always be certain points at which there will be freer approach for the water from above than at others, and from these points there will be some flow along the dam to the right and left. The water going over the crest of the dam will not, in other words, be at a uniform depth. Consequently the height to which the water will rise when the river is at a high stage will be somewhat above what would be calculated on the assumption that the overflow is uniform from end to end of the dam. Allowance for this fact has been made in planning the head-gate structures, bulkheads, and training walls, which are to be sufficiently high to avoid overtopping. The point at which there will be the greatest concentration of overflow over the dam should be maintained near its California end. The large diversion of water at that end of the structure will aid in drawing the stream in this direction.

If the suggestion to modify the crest of the dam is approved, it is proposed to depress a section of the crest, possibly 800 feet thereof, from 1 to 2 feet below the general level, thereby definitely fixing the point of greatest water concentration, which will have more or less effect upon the course on which most of the drift runs and may assist in keeping the same out of the canal. Furthermore, during high stages of the river, when due to the flow over the dam, an increased head is not required, such a depression would reduce somewhat the maximum water elevation above the structure.

At the California end of the dam, where the water is taken into the Yuma Canal, there are three large Stoney gates, closing openings 33 feet 4 inches wide, whose sills are about 13 feet lower than the crest of the dam. When these gates are raised, water from above the dam, flowing at high velocity, cuts out the sand and silt which have lodged in the desilting channel at whose lower end the gates are located. This desilting channel is separated from the river just above the dam by a rock fill spur or training wall. On the land side of this channel close above the Stoney gates is the head gate of the Yuma project canal. This is a simple structure with 35 openings, each 7.5 feet in the clear, between concrete piers which carry a concrete footbridge from which the flashboards, with which the flow of water is regulated, can readily be manipulated. The water drops into the canal over the top of these flashboards. By thus admitting water to the canal from the surface of the sluggish stream in the desilting channel much less silt is taken into the canal than would be the case if underflow gates were used. Once a week the sluice gates are opened and the sand and silt which has been deposited in the desilting channel is washed out, passing through the gates to the river below the dam. While no precise statement can be made of the amount of suspended material which is taken out of the water by this desilting process, it is generally estimated by representatives of the United States Reclamation Service to average about 50 per cent. In addition it is to be noted that practically none of the bed load of the river gets into the canal. All of this, together with the coarsest portion of the suspended load as above shown, is kept out of the canal by the desilting operation.

At the present stage of development in the Yuma project, with about 45,000 acres under cultivation and with a maximum canal flow of about 1,200 second-feet, the time required per week to free the desilting channel of deposits is three to four hours. During this time the sluice gates are open and the diversion of water into the canal ceases. This is of no inconvenience to the irrigators, who readily adjust their requirements to such a schedule. They have in fact thus far adjusted their demands to a shutdown of much longer duration than required for sluicing. The canal is being operated from early Monday morning to Saturday evening. Throughout Sunday the sluice gates are open and the canal bed is dry.

Under a full development of the Yuma project the desilting operation will have to be extended to a much larger flow of water. The maximum diversion for the irrigation of project lands will then be about 1,600 second-feet and, on the assumption that there should be no cooperation with Imperial Valley, there would have to be added to this flow about 4,000 second-feet to be used at some point near Araz for the generation of power. The power would be necessary to lift the water to the Yuma mesa, on which are located about 50,000 acres of project lands. The desilting channel would then be conveying from the river to the canal about five times as much water as heretofore, and there will have to be suitable enlargement of the diverting works and more frequent operation of the sluice gates.

Under cooperation with Imperial Valley the maximum diversion, as planned for the all-American canal, will reach about 10,600 second-feet. The present desilting channel has not been dimensioned either for this amount of water nor yet for that ultimately required for the Yuma project alone. It must be enlarged and extended. But the general plan of operation will remain the same. Periodically the sluice gates will be opened and the sand which has been deposited in the desilting chamber will be scoured out.

It is proposed as a part of the all-American canal work to allow space for a fourth Stoney gate inshore from those now in use. The desilting basin will be widened and extended farther upstream. It will be confined between two rock-fill training walls which, while gradually spreading apart, will curve out toward the river so as to leave a wide open mouth for the inflow of the canal water.

The present head gate will be replaced by a new structure of similar type having a length of about 1,374 feet. The upstream portion of this head gate will be constructed while the present one remains in service, and later the upper end of the new gate will be put into use during reconstruction of its lower end.

Based on the experience thus far at the Laguna Dam it is estimated that for desilting operations an amount of water not in excess of eight hours per week of the canal's flow will be required. Whether the desilting operation will be undertaken once a week or more frequently will depend not alone on the rate at which sand accumulates in the desilting channel, but also upon the effect which the resulting irregular flow in the canal will have upon the development of power and on the demands of the irrigators.

THE CANAL FROM LAGUNA DAM TO THE SIPHON DROP.

For 10.2 miles from Laguna Dam the canal will carry 10,600 second-feet of water, both for the Yuma project and the Imperial Valley, in the enlarged Yuma Canal. At the lower end of this 10-mile stretch on the present canal is a structure known as the Siphon Drop, through which the Yuma project water drops about 10 feet to the lower level at which it flows across the submersible river lands to the bank of the river opposite Yuma. The 6-foot superelevation of the canal banks will be such that with perfect safety the ordinary water-surface elevation could be increased. Furthermore, the operation of the system will probably require that dredges be kept in operation at certain points of the canal, and these can at any time, when the necessity therefor is apparent, be used to enlarge the canal prism and increase its capacity. The canal is to have a bed width of 162 feet. Its side slopes are planned at 1 to 1½ on the land side and 1 to 2 on the river side. When flowing full, the depth of water will be 16 feet. Its gradient will be 0.000079, or a little over 5 inches per mile. It has been so dimensioned that when flowing at capacity the mean velocity will be about 3.5 feet per second and that when its flow falls to one-half of the rated capacity the velocity will be at least 2.5 feet per second.

The enlargement of the Yuma project canal from its present dimensions is to be accomplished chiefly by raising the water surface and excavating in the bottom and on the land side of the present canal and placing the excavated material for the most part on the river side of the canal. A high broad bank of earth will thus be provided on which there should be both road and railroad track.

Within about 1¼ miles downstream from the Laguna Dam there will be three Stoney gates placed in this canal embankment which are to serve as sluice gates and as waste gates whenever occasion may arise. They will discharge back into the river and, together with a similar set which will be placed near Araz, will not alone serve their prime purpose as sluice gates but will also facilitate the discharge of storm water when there is large inflow from the hill region.

This provision for handling the storm water is suggested by the large reservoir capacity represented by the 17 miles of canal from the Laguna Dam to the proposed power station at Pilot Knob. All along this portion of the canal the left or river bank thereof will be a high embankment, as already described. Against this embankment water could rise 3 or possibly even 4 feet above the ordinary high-water line without serious menace. If a storm should occur near the head of the canal with a large delivery of water into the canal, such a rise might turn some water upstream, back into the desilting channel and thence into Colorado River.

While this is occurring, preparation would be made at all the sluice gates to open the same when necessary. The opening of those at the Laguna Dam would stop the inflow of river water into the canal, those near the 1¼-mile point and those near Araz would be opened to relieve the canal of storm water.

To prevent damage to the canal by the deposit in it of the coarse material which a cloudburst may sweep along in the beds of the sand washes which this part of the canal crosses, the canal will be closed where feasible against these by means of substantial embankments or barriers above which the flood occasioned by such a cloudburst will be pocketed. Interconnection will be provided so far as practicable from one sand wash to the next, and at selected points the barriers will be provided with concrete crests and protected slopes or drops to the canal, so that when the basin behind them is full they will discharge over the barriers into the canal. In this way a number of pockets will be provided for the interception of sand, gravel, and cobbles and these can hereafter be increased in extent by adding to the height of the overfall barriers.

THE CANAL FROM SIPHON DROP TO PILOT KNOB.

At the Siphon Drop the water from the Yuma project will be dropped, as explained, to a lower level, while the water for Imperial Valley will be held at grade. The all-American canal, strictly speaking, will begin at this point. It has been planned at a capacity of 9,000 second-feet. It will follow rather difficult ground, generally near and finally well in among the outlying hills and knolls which are features of the higher ground between a number of sand washes. An agreement will be necessary with the Southern Pacific Co., in order to secure permission to encroach on its right of way. In addition, a bridge will have to be provided for the main line on the Southern Pacific Railroad, and one for the Inter-California Railroad. In this section, too, the canal is to have a freeboard of at least 6 feet. At the lower end of this section there will be a rock cut, or tunnel, through a spur of Pilot Knob. Adjacent to and either above or below this spur the Pilot Knob power station will be located. At a convenient point below the power-house offtake there will be a controlling gate in the canal. By means of this the flow in the canal to the westward will be regulated. Any surplus water will be discharged either through the waste gates at Araz or through the power-house offtake canal and a by-pass which is here to be provided.

The canal throughout this section is to have a bed width of 150 feet, a depth of 15 feet, and side slopes varying from 1½ to 1 to the flatter slope of 2 to 1, the slope being adjusted to the varying character of the material to be excavated. The canal gradient will range from 0.0000786 to 0.0000862. In this section, too, when the canal is flowing at capacity the mean velocity will be about 3.5 feet per second.

CANAL LOCATION AT PILOT KNOB AND THENCE WESTERLY.

The range of hills which parallels Colorado River on its right or west bank in California terminates at Pilot Knob, which lies in the extreme southeasterly corner of California. While not very high nor of large surface extent, Pilot Knob is nevertheless a conspicuous topographic feature. This is due in a measure to its isolation. It is separated from the chain of hills and mountains to the north by a somewhat broken section of the mesa which forms the flat eastern slope of Imperial Valley extending from the base of this mountain range to the lower-lying Imperial Valley lands.

Pilot Knob is surrounded by this mesa formation on three sides—to the north, to the west, and to the south. On its remaining easterly side, its base has at times been washed by the waters of the Colorado River, and a spur of the mountain has been cut away to provide suitable foundation for the Hanlon gate with which, since 1906, the flow of water into the Imperial Canal has been controlled. Southward from Pilot Knob the mesa formation is much broken up by washes which have been cut deep and wide to an outfall upon the lower delta land of the river. The mesa elevation around the base of Pilot Knob is generally at or above 200 feet in elevation. The bottoms of the sand washes on the proposed canal line are generally at about 130 to 140 feet in elevation. Between them the remnants of the mesa, in long narrow ridges, with tops more or less broken, extend off toward the south into Mexico. The boundary line is just far enough south of Pilot Knob to leave space for a canal which, at the elevation attainable under use of Laguna Dam as the point of diversion, will cut through these mesa ridges and cross the intervening washes, with water grade practically at or slightly below the surface of the sand in the larger washes. At a point a little less than 2 miles from Hanlon's the canal will be out of this broken ground and the deep cut into the mesa will be continuous and uniform for about a mile and a quarter to the easterly edge of the sand hills.

Entering the sand area the course of the canal for another mile and a quarter will continue parallel with the boundary, being here located across an area over which low dunes are drifting. These dunes are irregularly distributed. Any course through them is as good as any other course. There was, therefore, no object in departing from a direct course westerly. But a continuation of this course would send the canal through a broad area of high sand ridges. It was found that by deflecting the course of the canal toward the northwest it could be kept for a mile in a location on which the surface of the sand was but little above the surface of the mesa and that one of the main sand ridges could then be pierced in a cut only a little over one-half mile in length westerly to a long narrow bare stretch of mesa surface which has been designated on the maps as Government Gap. The adopted canal location will follow this gap for 1½ miles to its westerly extremity. For three-fourths of a mile thence, still on a westerly course, the canal will cut through a mass of sand with a number of summits at elevations approximately 50 feet above the surface of the mesa. It is on this stretch of canal that the drifting sand is most likely to prove troublesome.

Upon leaving this three-quarter mile stretch the canal will be cut for about one-half mile through the westernmost ridge of sand, which crests on the canal line about 80 feet above the surface of the mesa and about 105 feet above the water surface of the canal.

On the entire canal stretch of about 10.5 miles through the sand-hill area, the canal will have to be cut deep into the mesa formation. This mesa formation underlies the sand everywhere. Its surface is smooth, with definite moderate slope from northeast to southwest. The canal, where it leaves the sand-hill area a few hundred yards to the northward of the watering station at the west end of the plank road, will be in a cut about 40 feet in depth. Its water surface will be 25 feet below the surface of the mesa. Its course will be slightly south of west from this point, with gradual approach to the international boundary.

As an alternative proposition, consideration has been given to a canal through the sand-hill area of smaller cross section, with higher velocity and with bottom and sides lined with concrete. The disadvantage of this alternative lies in the fact that the ultimate area to be irrigated by the canal must be taken into account at the time of construction, because when once constructed there can not well be any enlargement of a concrete-lined canal which must be kept in operation without interruption of service. The advantage of the lined canal lies mainly in the high velocity at which the water will be carried, thereby making sure that any sand and silt which gets into the canal will lodge elsewhere than in that portion of the canal in the sand-hill area, where the canal is deepest in the ground and where the removal of the sand would therefore be more difficult than from other portions of the canal.

A lined canal would be only about 70 feet wide on the bottom, its gradient would be about 0.00017, the velocity when flowing full would be about 6 feet per second, and its bottom would be from nothing to 6 feet lower than that of an unlined canal. Less excavation by about 6,000,000 cubic yards would be required in its construction, but the saving in cost from this reduction in yardage would be about offset by the cost of the concrete lining.

For further information on this subject reference should be had to the report of Mr. Preston, the engineer in charge of surveys.

At about 6 miles to the westward of the sand hills the canal will be out of deep cut and a proposed mesa canal can there be supplied with water. At this point it is proposed to turn out for use on the mesa and lands to the northward 3,000 second-feet of the canal flow. The remainder, or about 6,000 second-feet, will be dropped 24 feet through a near-by power house at mesa power station No. 1, located about 4 miles west.

About 3 miles westerly from this power station a low-level mesa canal, with a capacity of 500 second-feet, will be taken off and the remaining 5,500 second-feet will be held available for use in Imperial Irrigation District and on the west-side lands.

On this canal stretch, at about 5 miles westerly from the mesa power station No. 1, there will be a second power station. A fall of 47 feet can here be made available.

Beyond this point the construction of the canal offers no difficulties, but there will be several expensive structures required to carry the water across the deep Alamo and New River barrancas and to provide for the wastage of surplus waters.

At Calexico the canal will be located 1 mile to the northward of the boundary line. It can be held at an elevation sufficient to reach the west-side canal at a point about one-half mile northward from the international boundary. A few thousand acres of ground along the boundary line on the west side will be too high to be commanded by gravity flow. For the irrigation of these lands a pumping plant will be required.

The location of the canal is shown on Exhibit A, which accompanies Mr. Preston's report. On this sheet the locations of the various structures and the points at which the canal systems of Imperial Irrigation District are to be supplied with water from the canal are indicated. Thirty-seven maps on a scale of 400 feet to the inch have been prepared to show the topography along the route of the canal, but are too bulky for attachment hereto. One set will at once be furnished to the district and two sets to the Secretary of the Interior. More can at any time be made available.

COMPLETION OF SURVEY.

After submission of a preliminary report by this board under date of December 12, 1918, the studies in progress relating to character of material to be excavated and quantities to be handled were continued by Mr. Preston. The results of these studies have been submitted by him in a final report under date of June 17, 1919. He presents in this a revised estimate of quantities and cost, and presents the ascertained facts relating to the stratification and classification of the material disclosed by test pits and borings. Mr. Preston discusses in this final report the possible alternative of reducing the cross section of the canal where it is in deep cut on the mesa, by lining with concrete and increasing velocity, and he gives fuller information relating to the movement of the sand dunes which the canal crosses.

POWER DEVELOPMENT.

As already pointed out, there will be opportunity for the development of power at two points on the all-American canal. At the first, or at power station No. 1, there will be a drop of 24 feet to be utilized on the canal branch which is to serve the lands in Imperial Irrigation District and which will carry, in addition, about 500 second-feet of water for a low-level mesa canal. The installation at this point should be for the utilization of 6,000 second-feet of water in which, the lands outside of Imperial Irrigation District will have a small interest. At power station No. 2 the water intended for Imperial Irrigation District, or 5,500 second-feet, can be dropped 47 feet. The total water power, when the canals are flowing at capacity at these two stations, would be nearly 50,000 horsepower, of which, with suitable machinery, the peak utilization would be a little more than one-half, or about 25,000 horsepower, for the development of which suitable machinery should be installed.

The United States Reclamation Service proposes that some time provision shall be made for the development of power with the water of the Yuma project at the siphon drop. The utilizable fall at this point will be only 10 to 12 feet and the maximum flow in the Yuma Canal will be only about 1,600 second-feet. The amount of power here obtainable is not, therefore, large.

When the Yuma mesa is thrown open to settlement, water in large quantity must be pumped to an elevation of 56 to 80 feet above that of the project's lower canal system. Much more power will then be required than could be made available at the siphon drop. This power, if the Yuma project were developed independently without consideration of the requirements of the Imperial Valley, would be obtained, according to the tentative plans of the Reclamation Service, from a power station located at some convenient point near Araz. The water for power would be carried from the siphon drop on substantially the line which has been selected for an all-American canal to or beyond Araz, where it would pass through a power station with discharge either back into Colorado River or, under suitable agreement with Imperial Irrigation District, into the head of the Imperial Canal. The latter arrangement would be of advantage to the district because it would thereby be assured a supply of desilted water from the Laguna Dam. It would be of advantage to the Yuma project because there is less fluctuation of the water surface of the canal below its controlling gates than there is in the river. The power output would be larger at the summer high stages when the irrigation demand is at a maximum and when the most power will be needed, because the water in the canal is then considerably lower than the water in the river.

Under construction of an all-American canal before the Yuma project power canal is constructed, some plan of procedure should be agreed upon by which the Yuma project will be assured the power which it needs at no greater cost than that at which it could be obtained without cooperation.

It is possible, for example, that the first step toward an all-American or high-line canal into Imperial Valley will be the upstream extension of Imperial Canal to the Laguna Dam. Such a canal extension, barring accidents, which are only a remote contingency, would be useful in assuring to the Imperial Irrigation District an adequate supply of desilted water so long as there is a full supply of water in the river. As an upper section of an all-American canal it would be in use for several years during which the canal westerly from Pilot Knob is under construction, and during that time its water would be available and would in part be required to develop power which is required on the construction work.

This canal extension may be made either before or after the Yuma project power development is ready for execution. Or, it is possible that it will not be made until after the Yuma power canal is in use. This latter contingency is, however, so improbable that it will be be given no special consideration at this time.

When the all-American canal is completed its water will be carried westerly from Pilot Knob on as high a grade line as possible, and there will be no fall in this canal available for power at Pilot Knob.

The power station at Pilot Knob may be regarded as a temporary station to be used until the canal is completed. It will furnish the power required during canal construction. Its machinery may in whole or in part be later transferred to the mesa power station No. 1, where the available fall is practically the same as that which can be made available at Pilot Knob.

The Pilot Knob power station will be located near Pilot Knob at a point from which a tailrace can conveniently be connected with the present Imperial Canal below the Rockwood gate. In the canal, a short distance below the power offtake, there will be a set of regulating gates of the Stoney type and provision will be made for by-passing any water not required for power to the Imperial Canal, so that this canal may be fully supplied with water even when the water is not needed on the turbines of the power house. Any surplus water in the canal in excess of the power house and Imperial Canal requirements will be discharged through the waste gates located near Araz.

At the Pilot Knob power station there will be made available for power development, upon completion of the canal down to this point, the full head of water required by the Imperial Canal, or in round numbers about 6,000 to 7,000 second-feet. It is proposed to make the first installation of turbines adequate to use up to 3,000 second-feet of this canal flow. It is estimated that this will make about 9,000 water horsepower available for use in generating electricity whenever the flow in the canal is in excess of 3,000 second-feet. This should make in excess of 5,000 horsepower available for transmission by electricity to places of use and not less than about 4,000 horsepower when the demand for water by Imperial Irrigation District is at a minimum. Space will be provided for additional machinery so that power to the limit of the water supply can be developed if required. It is proposed, too, to provide space at this point for an auxiliary gas or steam plant for use in an emergency, so that if the output of electric energy should fail there will still be means at hand to generate the power needed for operating canal gates.

At both points selected for the generation of power on the mesa there will be offtakes from the canal through which the canal water can be sent to the power houses. There will also at each of these points be a set of regulating gates across the canal, of suitable type in combination with a drop to the tailrace level. The installation for power development will provide for the utilization of a maximum of about 16,400 water horsepower at the mesa power station No. 1 and for 29,400 water horsepower at the mesa power station No. 2. The power that will thereby be made available for delivery as electric energy will vary with the flow of the canal up to a maximum of 10,000 horsepower at the first and about 17,500 horsepower at the second station.

Whatever of this power may be required in connection with the pumping of water to the Yuma mesa and for canal operation or drainage pumps in both the Yuma and Imperial Valleys, should be held available for these purposes. The remainder should be marketed for the joint advantage of the Yuma project and the Imperial Irrigation District, provided, of course, that the Yuma project, or the United States for this project, has contributed to the cost of the power installations. In any event under joint development the power required by the Yuma project and by the Imperial Irrigation District should be paid for at cost plus a reasonable percentage, preferably 10 per cent, and the determination of cost should be made by the Secretary of the Interior. The apportionment of cost and the division of profits should be made substantially as set forth in this report. This board approves the general intent of the agreement already entered into between the United States and the Imperial Irrigation District (see Appendix, p. 67), under which both cost of construction of power plants and the resulting benefits are to be shared and under which there will be reserved to the Yuma project, upon suitable participation in the cost of construction, a proportional share of profits determined by the relation which 8,500 water horsepower bears to the total water horsepower for which a power plant is installed.

DISTRIBUTION OF COST AND OF RETURNS FROM POWER SALES.

This board has given consideration to the question of how the cost of alterations at Laguna Dam, of canal enlargement and canal extension, is to be distributed to power and irrigation, and it here presents also its conclusions relating to the apportionment of power and profits from power sales to the Yuma project and to the Imperial Valley.

The distribution of the cost of the canal work to power and to irrigation and the apportionment of the power cost thereupon to the Yuma project and the participating interest of the Imperial Valley presents peculiar difficulties. But if the broad principle be adopted of sharing the profits on the basis of capital invested by each party and the apportionment of cost is made on any fairly approximate but definite basis, full justice will be done to each.

The ultimate condition may, therefore, be taken into account to determine the apportionment of construction cost and of profits from power sales, regardless of what might otherwise be agreed upon for temporary or incomplete power installations. If it should then happen that either the Yuma project or the Imperial Valley fails to make actual contribution at the proper time of the full expected amount, then, temporarily, the other party, having contributed a larger share of capital, would, until this disproportion is adjusted, be entitled to a correspondingly larger share of profit.

The plans of the United States Reclamation Service for the Yuma project include a power development proposition. The Yuma Canal is to be enlarged to carry 4,000 second-feet in excess of the water required for irrigation, and this water is to be carried by canal a distance of about 5 miles beyond the siphon drop to some convenient point, as already stated, near Araz, a mile above Pilot Knob, where it would be dropped through a power house back into the river. It is expected that the fall which can there be made available at the height of the irrigating season would be about 23 feet. The board is informed that at such a power house to meet the requirements of the Yuma project alone there would have to be installed a plant for the utilization of about 8,500 water horsepower. These amounts of water and of gross water power may be accepted as representing the limit of the Yuma project's participation in any power development that may be found feasible on the all-American canal.

If there were no cooperation between the Yuma project and the Imperial Valley, the former would at the proper time have to make alterations at the Laguna Dam and to convey at its own expense about 4,000 second-feet of water to the vicinity of Araz, as above explained. A like expenditure would be incurred by the Imperial Valley if it should proceed unaided on its own account to make this amount of water diverted at Laguna Dam available at the same place for an all-American canal. In both cases the water would have been subjected to similar treatment in the matter of silt removal. In the one case it would be available for power, in the other, after the completion of the high-line canal, for irrigation, without any drop near Pilot Knob. During the time, however, that water is dropped into the present Imperial Canal the water used for power would also be available for irrigation. The fact, then, that the water can be had for either of the two purposes at Pilot Knob and that plans are on foot for its independent use for each purpose warrants the assumption, for cost distribution purposes, that the water has equal value for each use. A distribution of the cost of canal construction in equal amounts to each use would probably be as fair as cost distribution on any other basis. The cost, therefore, of bringing to Araz so much water as is used for power at Pilot Knob may be charged in equal amounts to power and to irrigation.

Furthermore, if on such a basis the Yuma project pays for an interest in the contemplated canal enlargement and canal extension, this interest and proportional share in the power output should be maintained even though the power house at Pilot Knob were abandoned and all the water were used elsewhere on the line of the all-American canal for power.

If there is cooperation between the Yuma project and the Imperial Valley interests, then any water brought into the vicinity of Pilot Knob for power should be dropped into the Imperial Canal and not into the river. The total fall which in such event can be made available is about 30 feet. The irrigation demand is likely to reach 7,000 second-feet at the head of the Imperial Canal before the all-American canal is completed. If the canal were to be constructed without cooperation between the Imperial Irrigation District and the Yuma project, there would be no cost apportionment. If, however, the Yuma project participates, as contemplated, in the canal extension and power-plant installation then the power installation at the Pilot Knob station should be adequate to meet not alone the canal construction requirements but also all possible immediate needs of both Yuma project and of the district.

While it appears reasonable to use the above facts as a means of determining how much of the cost of canal enlargement and extension should be charged to the Yuma project for an interest in power wherever developed, they do not afford an entirely satisfactory basis for determining how much of the cost of the full length of canal to the mesa should be charged to power. Where construction is made more expensive than it would be if the development of power were ignored, it would be proper to charge the increase in cost to power.

The need of water in large quantity at Araz by the Yuma project for power and by the Imperial Irrigation District to and beyond Araz for irrigation, each party being ready to construct canals independently, has led to an agreement (dated Oct. 23, 1918; see Appendix) relating to the division of the cost of a canal down to Araz when such canal is used jointly by the district and Yuma project. It is believed that in view of this agreement, which was entered into between the Secretary of the Interior and the board of directors of the Imperial Irrigation District, and under which the Yuma project will pay for a half interest in 4,000 second-feet of canal capacity to Araz, a similar basis should be adopted for ascertaining what part of the canal construction cost should be charged to any amount of water used for power at any point on the canal, where a fall equal to or in excess of that originally proposed by the United States Reclamation Service at Araz (23 feet) can be made available. There would thus be a distribution of the cost of the canal to irrigation and to power down to Araz. All canal construction costs below Araz would be charged to irrigation. Of the capacity of 9,000 second-feet for which the all-American canal has been planned, 6,000 second-feet will be used for power at mesa power station No. 1, dropping there 24 feet. Following the plan laid down in the agreement, power development, when the power plant is established at mesa power station No. 1 or at mesa power station No. 2 (with a fall of 47 feet), or at both of these, should be charged with that part of the canal cost down to Araz, determined by the ratio that one-half of 6,000 second-feet, or 3,000 second-feet, bears to the total capacity to be provided for Imperial Valley between the Laguna Dam and Araz, or 9,000 second-feet. This would make one-third part of cost of construction down to Araz chargeable to power.

This relation is of importance only in determining the amount of the construction cost which is to be charged to power and in computing the item of interest on the investment when determining the operating expenses of the power plants.

Yuma project is expected, as above stated, to require, ultimately, for power purposes at Araz 4,000 second-feet of water. It is also expected to install, if operating alone, a power plant at which the installation will be for 8,500 water horsepower. On the assumption that the distribution of canal construction costs down to Araz should be in the equal parts, for like canal capacities, as above explained to power and to irrigation, the charge to Yuma project for an interest in the canal should be as follows:

If the canal below siphon drop is constructed at a capacity of 6,000 second-feet, Yuma project should contribute one third of its cost down to Araz and would obtain the right to participate in any power output in the ratio of 8,500 water horsepower to the total water horsepower for the utilization of which an installation is made. The participation would, however, obligate the Yuma project to contribute to the cost of the power plant installation in an amount determined by this ratio and the same ratio would also determine the share of the Yuma project in any profits that result from the sale of power.

If the canal below the siphon drop is constructed at a capacity of 9,000 second-feet, Yuma project, again following the provisions of the agreement of October 23, 1918, should contribute two-ninths of its cost down to Araz. In that event the contribution of Yuma project to the cost of a power plant at or near Pilot Knob should again be determined by the ratio that 8,500 water horsepower bears to the total amount of water horsepower for which the plant is planned.

Should the power plant near Pilot Knob be abandoned in whole or in part and the utilization of the canal flow for power be transferred to the proposed mesa power stations, the same interest in the power should be reserved to the Yuma project as if the power plant were at or near Pilot Knob. The Yuma project should not, in that event, be required to duplicate its investment in a power plant. The cost of the transfer of any plant already established should fall entirely upon the Imperial Valley lands. But if the Yuma project has not contributed anything toward the cost of a plant at or near Pilot Knob, then, in order to effect the utilization of 4,000 second-feet of water for power and to participate in the profits from the sale of power, the Yuma project should contribute the same portion of the cost of the power plant at the mesa power stations as it would have contributed under participation in power development near Pilot Knob, and should be allowed to participate in the profits from the power output of these stations to a like extent. The cost of transmitting power for the Yuma project back to Pilot Knob, or to any other point that may be mutually satisfactory, should fall entirely upon the Imperial Valley both in the matter of first cost and operating and maintenance costs. The Yuma project would thus maintain any already established interest in the power wherever developed.

The participation of Imperial Valley interests outside of Imperial Irrigation District, as for example the east mesa area in an all-American canal project and in the power therefrom, should be on the following basis:

Imperial Irrigation District will be permitted, as set forth in the agreement approved by the Secretary of the Interior bearing date, October 23, 1918, to enjoy the benefits of a diversion at the Laguna Dam on condition that it pay to the United States in installments, without interest, $1,600,000 (which is about four-fifths of the cost of the structure). If, now, a larger area is to be served with water diverted at the dam than approximately 515,000 acres of net irrigable lands in the district, then the larger area should assume a proportionally larger part of the cost of the dam. The total net area of irrigable land in the Imperial Valley for which the all-American canal is planned, 900,000 acres, should bear in round numbers about nine-tenths of $2,100,856, the cost of Laguna Dam, or $1,900,000. This obligation would then be subject to apportionment on the basis of acreage within and outside of the district.

The lands in Imperial and Coachella Valleys outside of Imperial Irrigation District would have only a small interest in power because only the water of the lower mesa canal (500 second-feet) would be available for power at mesa power station No. 1. These lands should be charged with one-twelfth of the cost of making the power installation at mesa power station No. 1 this being the ratio of 500 second-feet to the full capacity of flow for the utilization of which the power installation is there to be made.

Power wherever developed should be made available to both the Yuma project and the Imperial Valley for pumping water, for irrigation, or drainage and for other canal operation and maintenance requirements, and there should be a charge for the power thus used at cost plus 10 per cent. Power in excess of such requirements, whether generated at a Pilot Knob power station or at the proposed mesa power stations, would be commercial power.

The cost of power development and its transmission should include interest on whatever capital investment has been charged to power down to Araz. Below Araz the canal may be regarded as constructed solely for irrigation purposes, with power development as an incident which is not to be charged with any further cost of ordinary canal construction. Accepting this view, the controlling gates and off-take gates and the chutes to lower levels at each power station would be chargeable to power. So, too, might be considered the extra cost of constructing the canal on a location such that its excess fall can be used for power. If not so located, however, other structures to take up grade would have been necessary. No attempt has been made to determine whether or not the local conditions would have justified any addition from this cause to the power-plant construction charge, and it is recommended that none be made.

Of the ordinary canal operating and maintenance expenses from the headworks at Laguna Dam down to the power station near Pilot Knob a small proportionate part to be fixed by the Secretary of the Interior should be charged to power, wherever this power is generated.

The canal operating and maintenance expenses from the Laguna Dam down to the siphon drop, which are chargeable to irrigation, should be distributed to the Yuma project and to the Imperial Valley interests, respectively, in the ratio of the relative amounts of water carried for each.

The distribution of profits from the sales of power should be to the Yuma project and to the Imperial Valley interests in the same ratio that is determined to be the basis of their relative contributions to the cost of constructing the power plants.

The agreement between the Secretary of the Interior and the Imperial irrigation district bearing date October 23, 1918, is in substantial agreement with the foregoing. The text of this agreement is appended to this report. Attention may be called to the wording of the clause in this agreement under which the cost of constructing power plants is to be apportioned. According to the agreement the Imperial irrigation district would be charged with one-half the cost even though the installation were limited to the maximum requirements of the Yuma project. The agreement apportions the cost of power-plant installation "to the Yuma project and the district, respectively, in the ratio that 8,500 water horsepower bears to the aggregate water horsepower of the plant installed." If the intent is to have the Yuma project bear such a portion of the cost as is represented by the ratio of 8,500 water horsepower to the total water horsepower for which a plant is installed, this would be in agreement with the board's recommendation. The language used in the agreement does not, however, permit this interpretation and should be modified.

THE CONTROL AND OPERATION OF WORKS IN WHICH THE YUMA PROJECT AND IMPERIAL VALLEY ARE JOINTLY INTERESTED.

The diversion of water from Colorado River at the Laguna Dam will be for the joint benefit of irrigable areas on both sides of Colorado River. It does not appear desirable that the entire canal system on both sides of the river should be under one management nor does any such arrangement appear possible. Separate organizations for the management of the Yuma project and for the management of the Imperial irrigation district will probably always be maintained. Other interests, too, will undoubtedly at some later time be supplied with water through headworks at the Laguna Dam and through a common main canal. Conflict of authority in the operation of all works for mutual benefit must be avoided. The maintenance and operation of the dam and diverting works and of the canal down to the siphon drop and of the power stations which are to be operated for the benefit of several interests should be permanently under the control of the United States.

The Secretary of the Interior, who directs the work of the United States Reclamation Service, should retain authority, or, if necessary, be given any additional authority, by agreement or otherwise, to operate and maintain the water diversion, to divide the waters between the Yuma project and the Imperial Valley interests, and to manage and control the power development and power sales from any plant in which both have an interest.

It would then fall to the Secretary of the Interior to apply the principles this board is recommending, relating to such questions as the distribution of construction costs to power and to irrigation, the apportionment of the canal and power construction costs to the Yuma project and Imperial Valley, the determination of interest and depreciation charges, the apportionment of irrigation operating expenses, and the division of profits from power sales and the like.

COST ESTIMATES.[1]

In adopting the schedule of unit prices noted in Mr. Preston's report, which is submitted as Part II of this report, consideration was given to the high level of prices of labor and materials reached during the war, and it has been assumed that the prevailing high prices will continue throughout the period of canal construction. The installation of the power plant near Pilot Knob is for use during construction, but it has been treated in the cost estimates as though it were a permanent feature of the project. Whether this is the case or not, its installation and use will make cheap power available for construction purposes, particularly on that part of the canal westward from Pilot Knob, thereby reducing the unit costs of excavation and other work below what they would otherwise be.

The estimates of the cost of constructing the canal from the Laguna Dam to Imperial Valley on a location entirely within the United States and the cost of making a connection between the present head of the Imperial Canal and the Laguna Dam are presented in detail in Mr. Preston's report.

According to the agreement of October 23, 1918, the apparent cost to the Imperial Irrigation District of acquiring from the United States the right to connect with the Laguna Dam is $1,600,000. The agreement provides that this sum is to be paid in installments (without interest). The last installment is to become due in 19 years. It is assumed by this board that if 400,000 acres of Imperial Valley lands not now within Imperial Valley Irrigation District are to be included in the area to be irrigated by a high line canal from Laguna Dam the amount to be paid to the United States on similar terms for the right to connect with the dam will be fixed at $1,900,000.

Mr. Preston has added these sums to his cost estimates. They should not be covered by any bond issue except possibly to the extent of installments which fall due at an early date. Being payments to be made at a future date they do not, strictly speaking, represent cost. The present value of $1,600,000 due as named in the agreement if discounted at 5 per cent is only about $975,000 and the present value of $1,900,000 payable in similar installments would be only $1,170,000. As presented in the engineer's report, the cost estimates which include these items of $1,600,000 and $1,900,000, respectively, when a bond issue or immediate requirements of funds are under consideration, may therefore be regarded as too large by about $625,000 in the one case and by about $730,000 in the other.

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[1] For details, see report of engineer.

A summary and analysis of the cost estimates is here presented:

Estimated cost of all-American canal, 9,000 second-feet capacity.

Estimated total cost of canal construction not including the item of $1,900,000 for the right to connect with the Laguna Dam nor the cost of power development	$27,655,091
Charge Yuma project with two-ninths of cost of canal to Araz, based on the relation of one-half of 4,000 second-feet to 9,000 second-feet, or two-ninths of $4,467,663	992,814
Charge Imperial Valley with balance	26,662,277
To which is to be added the obligation to pay in annual installments	1,900,000
Total, of which a part would be in deferred payments	28,562,277
The distribution of cost according to area to Imperial Irrigation District and to the mesa and other outside lands would be about as follows:	
Imperial Irrigation District about 60 per cent of $26,662,277, net canal construction cost	15,997,366
Imperial Irrigation District about 60 per cent of the item $1,900,000 (in annual installments)	1,140,000
Total, of which a part would be in deferred payments	17,137,366
Outside lands about 40 per cent of $26,662,277 net canal construction cost	10,664,911
Outside lands about 40 per cent of the item $1,900,000, in annual installments	760,000
Total, of which a part would be in deferred payments	11,424,911
The distribution of the cost of installing power plants at Pilot Knob and at mesa power stations Nos. 1 and 2 would be as follows:	
Estimated total cost of power plants	3,387,268
Charge Yuma project for power with about 40 per cent of what it would cost to install a power plant near Pilot Knob for the utilization of 6,000 second-feet falling 30 feet, or, in lieu thereof, with about 50 per cent of the cost of the power installation at mesa station No. 1 where 6,000 second-feet of water falling 24 feet are to be utilized, or 50 per cent of $1,231,523 (in round numbers)	616,000
Charge Imperial Valley for power, with balance	2,771,268
The distribution to Imperial Irrigation District and to the outside lands of the estimated cost of power installation, which is charged to Imperial Valley, should be as follows:	
Total estimated cost of installing power plants charged to Imperial Valley, as above	2,771,268
Charge outside lands a proportionate part of the estimated cost of mesa power plant No. 1 determined by the ratio that 500 second-feet provided at mesa power station No. 1 for the outside lands bears to the total capacity of 6,000 second-feet there provided for Imperial Irrigation District together with the outside lands, or one-twelfth of $1,231,523	102,627
Charge to Imperial Irrigation District the balance	2,668,641

The distribution of the estimated cost of canal construction, including power installation as between the Imperial Irrigation District and outside lands, would be as follows:

Charge Imperial Irrigation District with part canal construction cost, as above	$15,997,366
Charge Imperial Irrigation District with part cost of power plants, as above	2,668,641
Total	18,666,007
Charge Imperial Irrigation District with about 60 per cent of the item of $1,900,000, payable in installments	1,140,000
Total, of which a part would be in deferred payments	19,806,007
Charge outside lands in Imperial and Coachella Valleys with part of the canal construction cost, as above	10,664,911
Charge outside lands with part cost of power plants, as above	102,627
Total	10,767,538
Charge outside lands with about 40 per cent of the item of $1,900,000, payable in installments	760,000
Total, of which a part would be in deferred payments	11,527,538

Imperial Valley, including Imperial Irrigation District and all outside lands in Imperial and Coachella Valleys would be charged with the following for an all-American canal with a capacity of 9,000 second-feet, including the cost of power installation:

Part of net canal construction cost	26,662,277
Part of cost of power plants	2,771,268
Total	29,433,545
Right to connect with Laguna Dam, payable in installments	1,900,000
Total, of which a part would be in deferred payments	31,333,545

Yuma project would be charged with:

Part of canal construction cost to Araz, two-ninths of $4,467,663 as above.	992,814
Part of power-plant construction cost, about 50 per cent of $1,231,523 (in round numbers), as above	616,000
Total	1,608,814

The part of the total construction cost chargeable to power has been estimated as follows:

One-third of the cost of the canal to Araz, based on the relation of one-half of 6,000 second-feet to 9,000 second-feet, or one-third of $4,467,663	1,489,221
Estimated cost of power plants, covering construction power plant near Pilot Knob, mesa power plant No. 1 and mesa power plant No. 2	3,387,268
Total	4,876,489

Estimated cost of connection of Imperial Canal with Laguna Dam, 9,000 second-feet capacity.

Estimated cost of canal construction, being the cost of canal construction to the Pilot Knob power station ($4,880,258) plus the cost of a tail-race to connect with the present Imperial Canal ($91,080)	$$4,971,338
Charge Yuma project with two-ninths of cost to Araz (two-ninths of $4,467,663), as above	992,814
Charge Imperial Irrigation District with balance	3,978,524
Charge Imperial Irrigation District for right to connect with Laguna Dam, payable in installments	1,600,000
Total, chargeable to Imperial Irrigation District, of which a part would be in deferred payments	5,578,524
Estimated cost of power plant near Pilot Knob, based on the utilization of 6,000 second-feet of water falling about 30 feet (same as estimated for mesa power station No. 1)	1,231,523
Charge Yuma project with 40 per cent thereof, being in round numbers the ratio which 8,500 water horsepower bears to the total water horsepower for which the installation is made	492,609
Charge Imperial Irrigation District with 60 per cent thereof	738,914
The part of the estimated cost which is chargeable to Imperial Irrigation District of the construction of a connection between the Imperial Canal and the Laguna Dam, at a capacity of 9,000 second-feet, including a power plant near Pilot Knob, is as follows:	
Part cost of canal construction, as above	3,978,524
Part cost of Pilot Knob power plant, as above	738,914
Total	4,717,438
Right to connect with Laguna Dam, payable in installments	1,600,000
Total, of which part would be in deferred payments	6,317,438
The estimated cost, chargeable to the Yuma project for power to be generated at Pilot Knob is as follows:	
Part cost of canal construction, as above	992,814
Part cost of Pilot Knob power plant, as above	492,609
Total	1,485,423
The estimated cost of canal construction chargeable to power and to be used as a basis in figuring interest on the investment is as follows (connection with Laguna Dam, 9,000 second-feet):	
One-third of cost of canal to Araz, based on the relation of one-half of 6,000 second-feet to 9,000 second-feet, or one-third of $4,467,663	1,489,221
The gross construction cost chargeable to power, including power plants, will be about as follows:	
Estimated cost of Pilot Knob power plant based on a utilization of 6,000 second-feet of water for power	1,231,523
One-third of cost of canal to Araz, as above	1,489,221
Total	2,720,744

Estimated cost of all-American canal for Imperial Irrigation District, 6,000 second-feet capacity (alternative for information only).

Estimated total cost of canal construction, not including the item of $1,600,000 for the right to connect with the Laguna Dam, nor the cost of power development		$25,137,116
Charge Yuma project with one-third of cost of canal excavation to Araz, or one-third of $2,021,020	$673,673	
Charge Yuma project with two-ninths of cost of structures, or two-ninths of $1,855,496	412,332	
		1,086,005
Charge Imperial Irrigation District with balance		24,051,111
To which is to be added the obligation to pay in annual installments		1,600,000
Total, of which a part is in deferred payments		25,651,111
Estimated total cost of power plants		3,387,268
Charge Yuma project for power with about 40 per cent of what it would cost to install a power plant near Pilot Knob for the utilization of 6,000 second-feet of water falling 30 feet, or in lieu thereof with about 50 per cent of the cost of the power installation at mesa station No. 1 where 6,000 second-feet falling 24 feet are to be utilized, or 50 per cent of $1,231,523 (in round numbers)		616,000
Charge Imperial Irrigation District with balance		2,771,268
Imperial Irrigation District would be charged for a canal of 6,000 second-feet capacity, including power development:		
Part of net canal construction cost		24,051,111
Part of cost of power plants		2,771,268
Total		26,822,379
Right to connect with Laguna Dam, payable in installments		1,600,000
Total, of which part would be in deferred payments		28,422,379
Yuma project would be charged with:		
Part of canal construction cost to Araz one-third of $3,258,015		1,086,005
Part of power plant construction cost, about 50 per cent of $1,231,523		616,000
Total		1,702,005
The estimated cost of canal construction cost chargeable to power and to be used as a basis in figuring interest on the investment is as follows:		
Part cost of canal to Araz based on the use of the entire canal flow of 6,000 second-feet in generating power, or one-half of estimated cost of canal excavation ($2,021,020) and one-third of cost of canal structures ($1,855,496)		1,629,009
The gross construction cost chargeable to power, including power plants, would be about as follows:		
Estimated cost of power plants		3,387,268
Part cost of canal to Araz as above		1,629,009
		5,016,277

PLAN OF PROCEDURE.

This board believes that a high-line canal of large capacity from the Colorado River into the Imperial Valley, for the irrigation of lands in the Imperial and Coachella Valleys, is necessary and will sooner or later be constructed. Construction of an all-American canal by Imperial Irrigation District, under the agreement of October 23, 1918, which was ratified by the voters of the district on January 21, 1919, by a 3 to 1 vote, will be possible if the district is assured of financial assistance by the State of California or by the United States. The market for irrigation district bonds is limited and the district, in its present extent, can not hope to realize the desired result at an early date if it attempts to proceed unaided. The last bond sale of the district (in 1918) netted only 83½. The prospect of help from the State is, for the present, negligible. Of the 400,000 acres or more, outside of the district, which can be watered by a high-line canal from the Laguna Dam, a large part is still public domain. It is natural, therefore, that the Imperial Irrigation District and the outside lands, including Coachella Valley, should look to the United States for cooperation in carrying out the project. This cooperation can be had in various ways, of which this board suggests the following:

(*a*) The Government could undertake the construction of the works and retain permanent control of maintenance and operation, beginning at Laguna Dam and extending down to the point where any interests other than those of the Imperial Irrigation District are served, including all power development. Imperial Irrigation District should then pay a fair price for the water delivered to the district. The charge for water should be so fixed that capital will be returned and interest paid on any sum expended for the benefit of the district, whether on these works or on any storage works that may have to be provided for the district. The outside lands would be charged with proportionate per acre cost of works. Those in the public domain would be sold subject to this charge. Congressional authorization to proceed in this way would be required.

(*b*) The Government could undertake the construction of the works, retaining permanent control of maintenance and operation down to mesa power station No. 2, inclusive. The district should then issue bonds in the amount necessary to cover its proportional part of the cost. The Government should in this case arrange to accept the securities of the district, issuing its own in place thereof if necessary. The lands not in the district should, in this event, be charged with a proportional part of the cost, and suitable arrangement should be made by the United States to recover this charge, with interest, within a reasonable time, preferably 40 to 50 years.

(*c*) The boundaries of the Imperial Irrigation District could be enlarged so as to include or annex outlying lands and then bonds could be voted for the entire work. The bonds would be a lien on all the lands of the enlarged district. The Government should in in this case underwrite the bonds to make them marketable, or exchange its securities for the district's bonds under some suitable plan.

RECOMMENDATIONS.

The board recommends:

1. That the all-American canal, or an equivalent high-line canal, from the Laguna Dam into the Imperial Valley be constructed under one of the above-noted methods or under some other similar procedure for financing the enterprise, and that Congress pass such laws as may be necessary to put into effect any plan that may be agreed upon between the Secretary of the Interior and the Imperial Irrigation District.
2. That the connection of the Imperial Canal with the Laguna Dam be made at once.
3. That, so far as practicable, the water power of any canal that is constructed be utilized and the apportionment of the cost of installing power plants and of providing the necessary transmission lines should be made on the assumption that the tentative Government plans for the Yuma project would some day be carried out. The Yuma project on this assumption would maintain an interest and would be charged with the proportionate cost of canal capacity for 4,000 second-feet of water to near Araz, and it would be charged for power plant installation in the ratio that 8,500 water horsepower bears to the total water horsepower for which the power installation is to be made.
4. That the development of power with water from an all-American or high-line canal, regardless of the location of power stations, should be charged with such portion of the cost of canal construction down to Araz, and no farther, as is determined by the ratio that one-half of the capacity required for the water used for power bears to the total canal capacity.
5. In case that no other work be undertaken for the joint benefit of the Yuma project and Imperial Irrigation District, except the alterations at the Laguna Dam, the enlargement of the Yuma Canal and the extension of this canal to a connection with the head of the present Imperial Canal, then funds for this work should be provided either jointly by the United States for the Yuma project and by the Imperial Irrigation District, or by the United States alone subject to repayment of a proper proportionate part of the cost with interest by the Imperial Irrigation District, or by the Imperial Irrigation

District alone, subject to a participation in the power plant and power output by the Yuma project upon a repayment to the district of a proportionate part of the construction cost.

6. The power plant installation for construction and other purposes at Pilot Knob should, at the outset, be for the utilization of about 3,000 second-feet of water falling 30 feet, and space should be provided for a possible later enlargement of the plant.

7. The United States should undertake the early construction of storage reservoirs on the drainage basin of the Colorado River as part of a comprehensive plan for the betterment of the water-supply conditions throughout the entire basin of this river. The stored water should be made available for power and irrigation at a fair charge for this service. By storage on a large scale in well-distributed reservoirs the peak of the lower river's flood discharge will be cut down and the menace to the submersible lands along the Colorado River below the Grand Canyon, and in particular to the delta region and the Imperial Valley, will be reduced.

8. Negotiations should at once be entered into, through appropriate channels to bring about an understanding with Mexico, in reference to the control of Colorado River at its high stages on Mexican territory and in reference to the use of the river's water for irrigation in Mexico,and also to permit the United States to construct canals for the irrigation of lands in California across Mexican territory if found desirable to so locate them.

9. That funds be provided for a continuation of the studies relating to the movement of the blow sand on the line of the canal and that these studies be conducted under supervision of the United States Reclamation Service.

APPENDIX.

AGREEMENTS BETWEEN THE SECRETARY OF THE INTERIOR AND THE DIRECTORS OF IMPERIAL IRRIGATION DISTRICT.

AGREEMENT OF FEBRUARY 16, 1918, PROVIDING FOR THE APPOINTMENT OF THE ALL-AMERICAN CANAL BOARD AND THE MAKING OF SURVEYS.

CONTRACT.

This agreement made this 16th day of February, A. D. 1918, between the United States of America, by Franklin K. Lane, Secretary of the Interior, hereinafter called the "secretary," pursuant to the act of June 17, 1902 (32 Stat., 388), and acts supplementary thereto or amendatory thereof, and the Imperial Irrigation District, of El Centro, Calif., hereinafter called the "district," organized and existing under and by virtue of the laws of the State of California, by Leroy Holt, its president, its successors, or assigns,

Witnesseth: That—

2. Whereas it is desired to make a complete investigation, survey, and cost estimate of an all-American canal from the Laguna Dam, Arizona-California, into Imperial Valley, California; and

3. Whereas the said district will allot the sum of thirty thousand dollars ($30,000) to be made available upon condition that the United States will enter into a contract for said cooperative investigations with the said district; and

4. Whereas the secretary will allot the sum of fifteen thousand dollars ($15,000) to be expended on such investigations in cooperation with the said district:

5. Now, therefore, in consideration of the premises and the mutual covenants and agreements herein contained, it is stipulated and agreed between the parties hereto as follows:

6. That investigations, surveys, and cost estimates of an all American canal from the Laguna Dam, Arizona-California, into Imperial Valley, Calif., will be made in order to determine the possibility and feasibility of carrying an adequate supply of water for the irrigation of arid lands in the Imperial Valley; that such surveys shall be made in sufficient detail so that the character and cost of development shall be shown; such surveys shall also investigate the ways and means by which power may be developed as an incident to the construction of such irrigation works and the value and possible uses thereof.

7. All investigations, surveys, and cost estimates contemplated hereunder shall follow a general plan of operation jointly agreed upon by a board, one member to be selected by the district, one by the Director of the United States Reclamation Service, and a third by the University of California.

8. The surveys shall be made by an engineer duly appointed by the Director of the United States Reclamation Service, hereinafter called the "director," and the engineer shall be authorized to employ all necessary assistants and make all necessary expenditures. The engineer will make estimates of the amount of money needed for

each monthly period, and at least 15 days prior to the beginning of said periods will notify the said district of its proportion of the amount of money needed for use during the said period, and for the first period the said district shall pay to the United States five thousand dollars ($5,000), which sum shall be paid within 10 days after the execution of this contract. Upon completion of the said investigation the director shall make a statement of the actual cost and expense of the said investigation and surveys and submit the same to the district. The gross expenditure on the said work is limited to the sum of forty-five thousand dollars ($45,000), of which the district shall pay two-thirds and the United States one-third. All moneys paid by the district and all expenditures made under the terms of this contract shall be made to and by a special fiscal agent of the United States Reclamation Service at Yuma, Ariz.

9. If the said district shall fail to make prompt payments as required under this contract, the director, after 10 days' written notice to the district, shall have the right to cancel this contract, and all rights of said district thereunder shall cease, and the district shall not be entitled to repayment of any moneys expended on its account under this contract.

10. The employment of engineers, surveyors, and other necessary employees in connection with these investigations and surveys, together with the purchase or rental of equipment necessary, and all other necessary expenses for conducting said investigation, survey, and cost estimate will be charged as a part of the cost thereof.

11. On completion of the said surveys and investigations a report thereof shall be made by the engineer of the Reclamation Service in charge of the work. The facts and conclusions reported shall be reviewed by the board, provided for in article 7 hereof. The report of this board shall be published by the United States Reclamation Service. The expense of said report, which shall be printed, shall be deemed an item of expense to be paid under the provisions of this contract. This report shall contain detailed estimates, with suitable explanatory maps, plans, and other documents as exhibits, such expenses being segregated and itemized as far as practicable; that such report shall contain specific conclusions and recommendations as to the future policy.

12. No Member of or Delegate to Congress, or Resident Commissioner, after his election and appointment or either before or after he has qualified, and during his continuance in office, shall be admitted to any share or part of this contract or agreement or to any benefit to arise thereupon. Nothing, however, herein contained shall be construed to extend to any incorporated company where such contract or agreement is made for the general benefit of such incorporation or company, as provided in section 116 of the act of Congress approved March 4, 1909 (35 Stat., 1109).

In witness whereof this contract has been executed by the parties hereto, the day and year first above written.

UNITED STATES OF AMERICA,
By FRANKLIN K. LANE,
Secretary of the Interior.

[CORPORATE SEAL.]

IMPERIAL IRRIGATION DISTRICT,
By LEROY HOLT, *President.*

Attest:
F. H. MCIVER, *Secretary.*

AGREEMENT OF OCTOBER 23, 1918, PROVIDING FOR THE EXTENSION OF IMPERIAL CANAL TO THE LAGUNA DAM AND COMMITTING THE IMPERIAL IRRIGATION DISTRICT TO THE CONSTRUCTION OF AN ALL-AMERICAN CANAL.[1]

CONTRACT (DRAFT OF AUG. 1, 1918).

This agreement, made the 23rd day of October, A. D., 1918, by and between the United States of America acting in this behalf by Franklin K. Lane, Secretary of the Interior, hereinafter styled the United States, party of the first part, and the Imperial Irrigation District, a corporation duly organized and existing under and by virtue of the laws of the State of California, hereinafter styled the district, party of the second part,

Witnesseth:

2. Whereas, in connection with the Yuma project, Arizona-California, under the provisions of the reclamation act of June 17, 1902 (32 Stat., 388), and acts amendatory thereof and supplementary thereto, and particularly section 25 of the act of April 21, 1904 (33 Stat., 224), the United States Reclamation Service has constructed on the Colorado River a dam known as the Laguna Dam and certain auxiliary works, situate about 10 miles northeast of Yuma, Ariz., together with a main supply canal extending from said dam southwesterly to a point known as Siphon Drop, situate in section 10, Township 16 south, range 22 east, S. B. M.; and

3. Whereas under the aforesaid act of Congress the United States contemplates the reclamation of 120,000 acres of irrigable land, more or less, under the Yuma project with water from Colorado River diverted at Laguna Dam, and the district desires to change its point of diversion and secure the right to divert water at said dam for the irrigation of all irrigable land within the boundaries of the district; and

4. Whereas the district is authorized under chapter 160 of the Statutes of California, 1917, page 243, to contract with the United States for a supply of water for irrigation:

5. Now, therefore, in consideration of the mutual covenants and agreements to be kept and performed and considerations to be paid, as hereinafter provided, it is hereby agreed as follows, to wit:

6. That immediately on the execution of this contract the district shall proceed with diligence to secure data, which, together with other available data and data to be gathered under the existing cooperative contract dated February 16, 1918, will constitute a complete detailed survey with specifications and estimates of cost for the following:

(*a*) All necessary works and structures for the diversion of water from the Colorado River at Laguna Dam, thence through said existing main canal of the Yuma project, and sufficient enlargement and modification, including such works or devices as the Secretary of the Interior may require for the purpose of maintaining as near as may be the efficiency of the desilting and sluicing works at Laguna Dam, as such efficiency would be were the Yuma project fully developed, to divert and carry all water needed by the district for the irrigation of its lands above referred to, without impairing the utilization of said Laguna Dam, main canal, and auxiliary works to the full extent necessary to irrigate the Yuma project when fully developed.

(*b*) A main canal entirely within the United States, with all necessary appurtenant structures for the practical operation thereof, of sufficient capacity and proper construction to irrigate all lands in Imperial County, State of California, susceptible of economic irrigation from said canal. Such canal to connect with said main canal of the United States at a point described as Siphon Drop, and thence to connect with the canal system of said district in the United States upon the line located and approved, as provided by the terms of the cooperative contract of February 16, 1918, above referred to.

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[1] This agreement was ratified by the voters of Imperial Irrigation District on Jan. 21, 1919, by a vote of 2,535 in favor, 9,22 against.

7. Upon the approval by the Secretary of the Interior of the said survey, specifications, and estimates, district will provide for beginning and carrying to completion with due diligence, at the cost of the district, the work of construction and installation at the Laguna Dam and on the main canal, described in and contemplated by this agreement, and the district shall provide proper pecuniary support for the same in advance, in a manner satisfactory to the Secretary of the Interior. All such work shall be carried on in such manner as not to interfere with the proper operation of the Yuma project by the United States, and the district will promptly carry out any measures required by the United States or its authorized agents to avoid or relieve any interference with the delivery of water to the Yuma project during and due to such construction, and will save the United States harmless as to any claims for damages that may be presented by reason thereof.

8. All work of construction and installation, and the materials used therein, shall at all times be subject to the approval of the Secretary of the Interior, and be under the supervision and inspection of his authorized agents and engineers, to the end that the works shall conform strictly with said surveys and specifications, and such modification thereof as the Secretary of the Interior may approve in writing. In case any of said works are constructed under contract made by the district and are not in accordance with said surveys and specifications, the secretary may, at his option, replace such unsatisfactory construction work at the expense of the district, or stop said work of construction or cancel this contract, or resort to any other lawful remedy, and the decision of the Secretary of the Interior whether said surveys and specifications or modifications thereof have been complied with shall be final and conclusive. The district shall make complete detailed progress reports of the said construction work upon demand of the Secretary of the Interior. The cost of the inspection on the part of the United States provided by this section shall be paid by the district to the United States upon demand.

9. For the right to use the Laguna Dam, the main canal, and appurtenant structures, and divert water, as herein provided, the district agrees to pay to the United States the sum of $1,600,000 in 20 installments, the first of which shall become due and payable December 31, 1919, and subsequent installments annually thereafter. The first four installments shall each be 2 per cent., the next two installments each 4 per cent., and the next fourteen each 6 per cent. of the total amount. Upon failure of the district to make any such payment at the time and in the amount specified, then all rights under this contract shall be at an end, and all payments theretofore made shall become forfeited to the United States as liquidated damages; and as a further consideration for entering into this contract on the part of the United States, the district hereby releases and relinquishes any and all claims whatsoever for said moneys or any portion thereof so forfeited and paid as liquidated damages: *Provided*, That the Secretary of the Interior may in his discretion extend the time for any such payment upon the payment of 7 per cent interest in advance.

10. Subject to the provisions of the reclamation act of June 17, 1902 (32 Stat., 388), and acts amendatory thereof and supplementary thereto, the United States shall have and retain perpetually the title to and the complete control, operation, and management of said Laguna Dam, auxiliary works, and enlarged main canal from the dam to and including the siphon drop with appurtenant structures as enlarged, including the diversion works at siphon drop for the diversion and delivery of water to the Yuma project and the district. The district shall pay the United States, quarterly, on demand, April 1, July 1, October 1, and December 31, its proportionate share of the cost of operation and maintenance of said dam, auxiliary works, and enlarged main canal for the preceding quarter, such payment by the district to bear the same ratio to the total cost of such operation and maintenance as the amount of water received by the district at the point of delivery to the district's canal at siphon drop bears to the total amount of water carried in said main canal at that point plus

the amount of water diverted from the canal above the siphon drop for use on the Yuma project lands: *Provided,* That such extraordinary expense as may be caused by the operation of such desilting works as may be necessary to, as nearly as may be, maintain the efficiency of the desilting works at Laguna Dam, as such efficiency would be were the Yuma project fully developed, shall be borne by Imperial Irrigation District. Such extraordinary expense, if any, shall be determined by the Secretary of the Interior. If the district fails to pay to the United States within 30 days after rendition of bill, all operation and maintenance charges as determined by the Secretary of the Interior as they become due, the Secretary of the Interior, in addition to any other remedy which may be available to him for recovery of such charges, is authorized to shut off water from the intake of the district until such time as all sums due have been paid, with interest thereon at the rate of 7 per cent per annum, from rendition of bill.

11. The United States reserves the right to arrange for the connection with and use of Laguna Dam on such terms as the Secretary of the Interior may deem expedient, by any other irrigation enterprise, district, corporation, or individual; also of the headworks and main canal and other governmentally constructed works and works constructed jointly by these parties, after proper enlargement and modification, on terms herein stipulated, without, however, impairing the utilization of said dam, canal, and other works to the extent necessary to irrigate the lands within the boundaries of Imperial Irrigation District.

12. The United States reserves the right to develop power with the water in the enlarged main canal down to and including siphon drop. All other power possibilities in the main canal down to and including some convenient power site near Pilot Knob shall be developed by the United States to the extent deemed expedient by the Secretary of the Interior, at the joint expense and for the joint benefit of the Yuma project and the Imperial Irrigation District as herein provided. The apportionment of the cost of canal and headworks alterations and enlargement, and of canal extension from the Laguna Dam to the site selected for power development near Pilot Knob, shall be made to the United States (for the Yuma project) and to the Imperial Irrigation District, in the proportion that 2,000 second-feet bears to the total canal enlargement, less 2,000 second-feet. The cost of constructing power plants, transmission lines, and other power-plant accessories shall be also apportioned to Yuma project and the district, respectively, in the ratio that 8,500 water horsepower bears to the aggregate water horsepower capacity of the plant installed.

The operation and maintenance of any such power plant or plants constructed for joint benefit and the sales of power therefrom shall be under the control of the Secretary of the Interior, and charges for commercial power shall be upon rules adopted by the Secretary of the Interior applying equally to both valleys. Such power as in the judgment of the Secretary of the Interior is necessary for pumping and other operation and maintenance purposes shall be delivered to the Yuma project and to the Imperial Irrigation District at the cost of development thereof, plus 10 per cent, said cost to include interest at 5 per cent per annum on the capital invested in power plants, transmission lines, and power-plant accessories, and also a proportional part of the headworks and canal enlargement from Laguna Dam to Pilot Knob, determined by the relation 2,000 second-feet bears to the total enlarged canal capacity and reasonable depreciation as may be determined by the Secretary of the Interior. The preference right to purchase power developed at the price herein specified shall be given over other uses of power, to the requirements of the Yuma project (limited to an area not exceeding 120,000 acres) for power to be used in pumping irrigation water. The profits from power sales or power leases shall be divided between the Yuma project and the Imperial Irrigation District in the proportion of their respective investments in power plants, transmission lines, and power-plant accessories, and in the canal and headworks alterations, canal enlargement, and canal extension from the Laguna

Dam to and including the power-house site near Pilot Knob, to be determined by the Secretary. In case capacity be also provided by enlargement for the irrigation of lands in the United States outside of the Imperial Irrigation District, then the cost of enlargement computed as above as chargeable to the Imperial Irrigation District shall be borne by such district and such other lands in the ratio of their respective irrigable acreages. The cost of any works used jointly by several irrigation enterprises below the point near Pilot Knob where power is developed shall be apportioned equitably by the Secretary of the Interior. No water shall be diverted for power purposes from such main canal below siphon drop at any time when such water shall be required for irrigation of lands being irrigated therefrom in Imperial County.

13. It is understood and agreed that the connection with Laguna Dam herein provided for is to be constructed as a part of an all-American canal, which the district hereby agrees to build at as early a date as possible and within reasonable time; and when the district shall have completed said all-American canal it shall have the right to drop water at some other point than the vicinity of Pilot Knob for power development, and in this event agrees to place at the disposal of the United States at Pilot Knob, or some other point to be agreed upon, such power in addition to that generated at Pilot Knob as in the judgment of the Secretary of the Interior is necessary for pumping and other irrigation operation and maintenance purposes of the Yuma project or any auxiliary thereof, not in excess of 8,500 water horsepower in the aggregate, at the cost of development thereof at the power house, plus 10 per cent, said cost to include interest at 5 per cent and reasonable depreciation as determined by the Secretary of the Interior. All power development, operation, and maintenance of power plants on the all-American canal, and sales of power, shall be under the control of the Secretary of the Interior, and charges for commercial power shall be upon rules adopted by the Secretary of the Interior, applying equally to both Imperial and Yuma Valleys. The profits from commercial power shall be divided between the Imperial Irrigation District and the Yuma project in ratio of their respective investments in power, including the enlargements, alterations, and extensions of the headworks and main canal down to and including the power-house site near Pilot Knob, plus investments in the power plants, power house, transmission lines, and other accessories. In dividing profits, the district shall be credited with the net revenue from the amount of power by which the total power output is increased by the all-American canal west of Pilot Knob, which shall be determined by the Secretary of the Interior. Power delivered to Imperial Irrigation District for pumping and other irrigation operation and maintenance purposes shall be delivered on the same terms as power delivered to the Yuma project for said purposes.

14. It is understood and agreed that the Secretary of the Interior shall control the division of water and shall divert for use of the Yuma project or any auxiliary thereo as heretofore or hereafter undertaken by the United States within the present boundaries of the United States and not exceeding 120,000 acres sufficient water to secure the permanent and economical reclamation thereof, not exceeding, however, one-quarter of the water in the river above Laguna Dam. The foregoing applies only to the natural flow of the Colorado River, and not to storage water, which shall be delivered to the party entitled thereto.

The United States makes no guaranty or representation as to the quantity of water that may be available without storage for delivery to the district under this contract and shall not be responsible for failure to deliver water under this contract caused by insufficient supply of water in the Colorado River, hostile diversion, or drought, interruption made necessary by repairs, nor on account of any valid order or decree of a competent court; nor for any damages by floods, acts of hostility, or unavoidable circumstances; nor for loss of crops or other damage caused by nondelivery of water.

15. It is understood and agreed that the district shall have the right at any time to extend its boundaries within the United States and water additional lands upon pay-

ment of same amount per acre as irrigable lands in present Imperial Irrigation District are to pay under terms of this contract. This right to be also available on same conditions to Yuma project, additional to 120,000 acres herein mentioned. All proceeds from payments on account of initial connection charges assessed to and collected from such new lands shall be used under the direction of the Secretary of the Interior for the construction of storage works for the benefit of the lands contributing.

16. This contract shall not become effective until the same shall have been duly ratified and confirmed, in accordance with law, by a vote of the people of the Imperial Irrigation District, and unless it shall be so ratified within six months from the date of execution hereof by the Secretary of the Interior it shall become void and of no further effect.

17. In case of failure on the part of the district to provide for beginning the work of enlargement of the Yuma main canal within two years from the date hereof, the Secretary of the Interior shall have the right to abrogate this contract.

18. No Member of or Delegate to Congress, or Resident Commissioner after his election or appointment, or either before or after he has qualified and during his continuance in office, and no officer, agent, or employee of the Government shall be admitted to any share or part of this contract or agreement, or to any benefit to arise thereupon. Nothing, however, herein contained shall be construed to extend to any incorporated company, where such contract or agreement is made for the general benefit of such incorporation or company, as provided in section 116 of the act of Congress approved March 4, 1909 (35 Stat. L., 1109).

In witness whereof the parties hereto have caused the execution of these presents as of the day and year first above written.

THE UNITED STATES OF AMERICA,
By FRANKLIN K. LANE,
Secretary of the Interior.
IMPERIAL IRRIGATION DISTRICT,
By LEROY HOLT.

Part II.

REPORT TO THE ALL-AMERICAN CANAL BOARD.

By Porter J. Preston, *Engineer in Charge of Surveys and Examinations.*

Yuma, Ariz., *June 17, 1919.*

To the All-American Canal Board:

INTRODUCTORY.

(*a*) A contract was entered into by the Secretary of the Interior and the directors of the Imperial Irrigation District on February 16, 1918, for a "complete investigation, survey, and cost estimate of an all-American canal from Laguna Dam, Arizona-California, into the Imperial Valley." The contract further provides, "in order to determine the possibility and feasibility of carrying an adequate supply of water for the irrigation of said lands in the Imperial Valley that such surveys shall be made in sufficient detail, so that the character and cost of development shall be shown"; such surveys shall also investigate the ways and means by which power may be developed as an incident to the construction of such irrigation works and the value and possible uses thereof.

(*b*) Under the terms of the contract and the conditions now existing concerning the irrigation system of the Imperial Irrigation District, the cost of development above mentioned seems to refer to a main canal heading at Laguna Dam and connecting with the main distributing canals of the irrigation district. Our investigations were therefore confined to a survey and investigation of this main canal from Laguna Dam to connect with the west-side main canal, and thereby intercepting all the other distributing canals of the irrigation district and at the same time being able to serve the new lands from properly designed distributing canals.

(*c*) A study was made of the available data in the Yuma office of the United States Reclamation Service, and early in March, 1918, a survey was commenced. Frequent meetings and conferences have been held with the board and individual members of the board from time to time, and their counsel and advice, aside from their official duties under the contract, have been of material assistance in the work of making the surveys and the preparation of this report.

PRELIMINARY REPORT.

(*a*) On December 7, 1918, a preliminary report was made to the board of engineers in order to furnish certain information to the Imperial Irrigation District.

(*b*) The board of directors of the Imperial Irrigation District entered into a contract with the Secretary of the Interior on October 23, 1918, for a connection with Laguna Dam and for the construction of an all-American canal upon the line located and approved as provided by the terms of the cooperative contract of February 16, 1918. Under the terms of the above-named contract of October 23, 1918, it was necessary to submit the contract to a vote of the irrigation district for their ratification within six months from the date of signing. The directors of the Imperial Irrigation District, wishing to submit the contract to a vote at an early date, requested that a preliminary report be made in order that they might be able to place all the information possible before the people of the irrigation district.

(*c*) The present report is to a large extent a repetition of the preliminary report, with some slight modifications in the estimates of cost and some additions.

EARLIER SURVEYS.

(*a*) Several surveys and estimates have heretofore been made for the purpose of diverting water at Laguna Dam into the Imperial Valley and onto the mesa lands by what has been termed a high-line canal. These surveys followed along the route and contemplated the enlargement of the present Yuma main canal from Laguna Dam to siphon drop, and thence along the base of the hills bordering the valley from this latter point to the Southern Pacific main-line track. From this point the surveys followed the right bank of the Colorado River, generally parallel therewith and but a short distance from the river bank, to a point near the international boundary line. From this latter point the plans followed by the several surveys have differed to some extent and are described below in more detail.

(*b*) In 1903 and 1904 the United States Geological Survey made a topographic survey of the Yuma project on the California side of the river, extending the topography to the international boundary, and thence westerly for about 2 miles, covering a strip along and parallel with the boundary and about 500 feet in width.

(*c*) In 1908 the Reclamation Service made a topographic survey of the greater portion of the mesa east of the present Imperial east high-line canal as far north as the Southern Pacific Railroad. At this time some preliminary lines were run for a high-line canal south of the sand hills through Mexican territory.

(*d*) In 1913 the Imperial Irrigation District made a preliminary survey for an all-American aqueduct of a capacity of about 3,667 second-feet through the sand hills. This survey followed along and parallel with the international boundary from a point just west of Hanlon heading to a point near the present east high-line canal.

(*e*) In 1916 and 1917 the Imperial-Laguna Water Co. made surveys for an all-American canal along practically the same route followed by the Imperial Irrigation District in 1913, except it only extended westerly to a point where the mesa lands could be served. The early plans of this company contemplated a canal of 1,865 second-feet through the sand hills. Later the company planned a canal of 4,100 second-feet capacity.

(*f*) The data and maps of these different surveys were available and have been made use of in making the surveys and estimates.

SURVEYS.

(*a*) In 1917 a survey was made by the Reclamation Service for a power canal from Siphon Drop to a proposed power site near Araz. Very careful and complete topography had been taken over this section. The previous year cross sections had been taken on the main Yuma Canal from Laguna Dam to Siphon Drop. It was found that we could use all of this work, and therefore the survey was taken up at the end of the proposed power canal near Araz and extended southwesterly to a point on the east side of Pilot Knob. At this point it will be necessary to either construct a large-sized tunnel or an open cut for about 800 feet through a rocky spur of Pilot Knob which projects out to the east from the main mountain. This is the only feasible route and is necessary in order not to interfere with the Imperial Irrigation District's quarries.

From this point the line continues in the same general course to a point 400 feet north of the international boundary and thence parallels the boundary to a point well within the blow-sand area. From this point the line runs to the northwest, keeping well on the mesa floor among small sand dunes not exceeding 12 or 15 feet in height. At a point about 2 miles north of the international boundary the line takes a southwesterly course through an open mesa for more than a mile and then again swings to the northwest through a high blow-sand ridge for 3,000 feet, entering another open mesa, locally known as Government Gap. Passing through this mesa from east to west for about 1½ miles, the canal takes a southwesterly course, crossing two main sand ridges totaling about 1¾ miles, where it emerges onto the east side mesa with a water surface about 25 feet below the level of the mesa, continuing this same course until it reaches a point 400 feet north of the international boundary, thence along the boundary to international monument No. 213, where the line runs somewhat north of the boundary, keeping generally a westerly course, in order to take advantage of the topography of the ground. As the line nears the east-side high-line canal it again approaches the boundary and follows along it to the west-side main canal, except for a detour in order to get around the city of Calexico, and to obtain a better crossing of New River. The general map of the all-American canal (Exhibit A) shows the location of the canal from Laguna Dam to the west-side main canal. The map shows the approximate location of canal structures and other prominent features adjacent to the line.

(*b*) Throughout the blow-sand areas two alternate routes were surveyed, one along the boundary, which is about 1¾ miles shorter than the line above described but contains 1,800,000 cubic yards more excavation. The second, to the north of the adopted line, was surveyed for the purpose of avoiding the first big sand ridges described above. This line is about one-half mile longer, but contains 200,000 cubic yards less excavation (see Exhibit A).

(*c*) Topography was completed and extended on the section south of Pilot Knob, and a strip of topography 2,000 feet in width was taken on the lines through the sand hills. Additional topography was taken at Laguna Dam, along the Southern Pacific tracks near Araz, Alamo River, and New River crossings.

(*d*) All the topography taken and available was plotted on a scale of 400 feet to the inch. This is shown on 37 sheets which are on file in the Yuma office. A profile of the canal from Siphon Drop to the west-side main canal on a scale of 500 feet to the inch is also on file in the Yuma office.

IRRIGABLE ACREAGE.

(*a*) The irrigable acreage of the Imperial Irrigation District now within the district boundaries is about 515,000 acres, all of which can be reached by gravity through an all-American canal, with the exception of two or three sections near the international boundary west of New River, upon which it will be necessary to pump the water. The west-side main canal can be made to serve another possible 40,000 acres.

(*b*) In the east-side mesa district there is estimated to be 140,000 acres, and to the north of the Southern Pacific Railroad, east and north of the Salton Sea, including the Coachella Valley there is another 200,000 acres, making a total of 895,000 acres that can be served by a gravity system.

(*c*) In consultation with the board of engineers, it was decided to adopt 900,000 acres as the basis upon which to make the estimates.

WATER DUTY.

(*a*) In designing the capacity of a canal to serve 900,000 acres of land the maximum amounts required and the canal losses are the main factors to be considered. A study of the water deliveries on the

Yuma project from 1912 to 1918, inclusive, show that the average amount delivered to the land was 3.74 acre-feet per acre and the maximum required in any one month, averaging the years, was 13.3 per cent, or 0.48 acre-foot per acre, as shown by the accompanying table. It must be remembered that during the period covered by the table the Yuma project was bringing new land under cultivation each year, which required more water than the older irrigated lands. With as large an acreage as we have here under consideration and considering that so large a portion of it is land that has been under irrigation for a number of years, it has been considered that a duty of 3.33 acre-feet per acre to the land will be ample. If it is assumed

Water deliveries to lands of Yuma project.

Month.	1912		1913		1914		1915	
	Per cent.	Acre-feet.	Per cent.	Acre-feet.	Per cent.	Acre-feet.	Per cent.	Acre-feet.
January	3.9	0.18	1.6	0.07	5.4	0.20	3.1	0.10
February	8.9	.41	7.1	.31	3.9	.14	.9	.03
March	7.6	.35	8.7	.38	9.2	.34	12.1	.40
April	8.5	.39	9.9	.43	9.0	.33	9.8	.33
May	9.6	.44	9.9	.43	10.0	.37	8.0	.27
June	9.2	.42	12.2	.53	11.9	.44	13.1	.44
July	10.9	.50	14.0	.61	11.9	.44	12.5	.41
August	13.5	.62	11.7	.51	12.2	.45	12.7	.42
September	11.1	.51	10.6	.46	13.2	.49	11.9	.40
October	7.4	.34	6.7	.30	7.1	.26	7.7	.26
November	4.8	.22	3.7	.16	2.7	.10	6.2	.21
December	4.6	.21	3.9	.17	3.5	.13	2.0	.07
Total	100.0	4.59	100.0	4.36	100.0	3.69	100.0	3.34

Month.	1916		1917		1918		Mean.	
	Per cent.	Acre-feet.	Per cent.	Acre-feet.	Per cent.	Acre-feet.	Per cent.	Acre-feet.
January	2.3	0.07	1.6	0.06	1.43	0.05	2.7	0.10+
February	3.9	.12	5.4	.20	1.84	.06	5.1	.19+
March	8.6	.28	9.9	.37	9.38	.31	9.4	.35−
April	9.7	.31	9.8	.36	10.09	.33	9.4	.35−
May	10.3	.33	11.3	.42	9.23	.30	9.9	.37−
June	13.9	.45	11.9	.44	12.05	.40	12.0	.45−
July	12.1	.39	12.7	.46	17.40	.57	12.8	.48+
August	15.1	.48	13.9	.48	16.94	.56	13.3	.50+
September	11.4	.36	11.5	.43	12.71	.42	11.8	.44−
October	6.8	.22	7.4	.28	6.82	.22	7.2	.27−
November	3.8	.12	1.7	.09	1.07	.04	3.5	.13−
December	2.1	.07	2.9	.11	1.04	.04	2.9	.11−
Total	100.0	3.20	100.0	3.70	100.0	3.30	100.0	3.74

that the maximum to be delivered in any one month does not exceed 13.5 per cent of the whole, then 0.45 acre-foot per acre per month delivered to the land will be sufficient. The losses in the canals are not anticipated to be excessive after they are thoroughly seasoned. The present practice of the Imperial Irrigation District is to deliver the water to the mutual companies with an allowance of 10 per cent for losses in the distributing canals. The losses for 1915 as based upon the whole year seem to be in excess of this amount, but taking the losses during the three maximum months of June, July, and August the losses in the distributing system seem to be less than 10 per cent of the amount of water diverted at Hanlon's heading. During these same months the losses from Hanlon's heading to the point of delivery into the mutual canals average nearly 21 per cent, but during the month of maximum discharge there is considerable overflowing of the canal banks and ponding, which increases the losses considerably.

(*b*) During the season of 1913 the Reclamation Service made some measurements for the loss of water due to seepage upon some of the main canals and laterals. These results gave a loss of 0.64 foot in depth per 24 hours for the larger canals to 2 feet for the smaller laterals, with a mean of 1.17 feet for all the observations.

(*c*) Assuming a loss of 1.2 feet in depth over the wetted perimeter per 24 hours would give the following losses for a canal from Laguna Dam to the Alamo River: Laguna Dam to siphon drop (of amount diverted), 170 second-feet, or 1.6 per cent; siphon drop to Pilot Knob (of amount at siphon drop), 112 second-feet, or 1.25 per cent; Pilot Knob to east-side mesa canal (of amount at siphon drop), 286 second-feet, or 3.2 per cent; east-side mesa canal to the Alamo River (of amount at siphon drop), 206 second feet, or 2.3 per cent; a total loss of 774 second-feet from the Laguna Dam to the Alamo River, or 7.3 per cent of the amount diverted at Laguna Dam. It is the intention to have the canal of sufficient capacity, with a 6-foot freeboard, to care for all the storm waters entering the canal from Laguna Dam to Araz where the excess water may be wasted, There are certain seasons of the year when the canal would be free of any danger of flood waters, and at a season when there is excess water passing over Laguna Dam it may be desirable to crowd more water into the canal. Occasions will also arise when one portion of a system will require more water than another. For these reasons it was deemed as well for this estimate to figure the canal capacities as though there were no losses in the canal due to seepage and evaporation.

(*d*) In a report made by Elwood Mead, D. C. Henny, and Joseph Jacobs on Irrigation and Flood Protection Problems of the Imperial Valley, California, dated March 5, 1917, they concluded that all the losses could be reduced to 25 per cent. (See Exhibit H of their report.) This seems to be a reasonable assumption when the maximum capacity of the canal is under consideration. Upon this basis, the maximum diversion at Laguna Dam would be 0.60 second-foot per acre, or a duty of 1 second-foot for 100 acres.

BLOW SAND.

(*a*) The canal will have a length of 10.1 miles through the blow-sand section. The first 6½ miles is through a region of low sand dunes and open mesa. The sand dunes do not exceed 12 to 15 feet above the mesa floor and are moving over the mesa in the general direction of northwest to southeast. The sand is of a very fine character, 99 per cent of which will pass a No. 50 sieve. The open mesas are of small area, except the last mile of this section, upon which there are very few sand dunes moving. The next 0.7 mile is mainly through a sand ridge, which reaches a height of 100 feet above the mesa floor on either side. This sand is of the same general character as the smaller dunes, but as a whole has a much smaller movement. For the next 1.4 miles the canal is through an open mesa with only here and there a small moving dune on its surface, but throughout this length it is flanked on both sides by high sand hills reaching an elevation of more than 200 feet above the mesa floor. The last 1¾ miles is across two main sand ridges, reaching elevations of 50 and 80 feet above the mesa floor, with practically no open mesa. The easterly one of these ridges consists of a number of more rapidly moving dunes upon the more stable sand of the two flanking hills mentioned in the preceding section. At this point the two flanking hills come together and completely cover the mesa floor. The last of these ridges contains a much coarser-grained sand on the surface, which requires a stronger wind to set in motion.

(*b*) Early in the fall of 1918 a few areas and cross sections were selected and carefully mapped and measured in order to study the direction and rate of movements of the blowing sand. The test pits were also left open to catch the drifting sands and measurements made to detect the rate of filling up. In connection with these investigations the daily wind records of the United States Weather Bureau at Yuma, Ariz., for the past several years have been collected and plotted. The investigations have not as yet covered sufficient time to lead to definite conclusions upon the movement of the drifting sand, but the following general facts have been shown:

1. The fine sand on the eastern and central portion of the main sand ridge moves with winds exceeding 10 miles per hour, and on the west portion it takes a somewhat stronger wind to set the coarser-grained sand in motion, and there is a smaller quantity moved with a given wind velocity than on the central and eastern portion.

2. That the general movement is in the direction of the resultant of the winds and is in general from a little west of northwest to a little east of southeast.

3. That by far the larger portion of the sand moves in the form of small dunes. These traveling dunes are often upon the surface of the larger sand hills. They usually form upon the northwest side of the main sand hill from the sand of the main hill on its windward side, gradually moving across the surface of the larger hill and finally losing its identity on the leeward side of the crest in the main sand hill. In the eastern portion of the sand ridge the dunes are usually small, moving upon a practically level sandy mesa floor.

4. On the windward side, the sand dune has a very flat slope up to about 3 to 1 and on the leeward side as steep as 1.75 to 1.

5. The larger portion of the moving sand moves in the first 2 or 3 feet of air above the surface of the sand dune in the same manner as the bed load of a stream is carried, and after being blown over the crest falls on the leeward side near the top, the bottom building forward by the sand sliding down the steep leeward slope.

6. The smaller in height a sand dune is the faster it moves. There are constant and numerous variations and exceptions to the above, because of the variable direction of the wind. The general movement of the sand dunes is shown from a study of the advance of the blow sand from the mesa formation to the alluvial bottom of the Colorado River, along the southern end of the sand ridge in Mexico. This is shown in figures 1 to 3, Exhibit D. The areas surveyed and mapped early in the fall have been resurveyed all a second time and part the third time. The several successive surveys show some movement and in general it is in the direction of the prevailing wind, but the results have not as yet been sufficient to determine the rate of movement nor to deduce any definite conclusions. The second measurements of the cross sections on the big sand hills show some movement toward the southeast in some portions of the cross sections. However, these have not as yet been observed long enough to ascertain their rate of movement. The open test pits have shown no filling in as yet. However, they were nearly all located in protected places on the mesa floor at some little distance from any sand dune, so that a negative result here shows very little if any value as to the movement of the sand.

(*c*) Exhibits Q to T,[1] inclusive, show the wind movement at Yuma for 1917 and 1918 and the resultant direction of the wind for these years. Several methods have been considered to prevent the sand from blowing into the canal and to remove the amount that may blow into the excavated section. In Egypt the movement of the sand is retarded by building barriers with wire and cotton stalks or other similar material as a temporary means and by the irrigation of the sand areas, upon which grass and other shrubs are started. The soil of the mesa is composed of sandy material with sufficient gravel mixed in so that when distributed in the spoil banks it will be stable from any wind movement. These spoil banks are to be spread out so as to cover a strip as wide as construction methods will permit on each side of the canal. During the period of construction and the first years of operation, temporary barriers will be necessary, or the sand that drifts behind the spoil banks upon the 30-foot berm or into the canal must be removed. To cover this item during the period of construction we have roughly estimated 500,000 cubic yards will have to be so moved from the canal prism. When the canal is in operation the area for 1,000 to 1,200 feet behind the spoil banks can be irrigated by pumping, so that grass and shrubs may be started, to hold the drifting sand. This method can not be practiced through the three large sand ridges. The sand entering the canal prism in these sections can either be removed by suction dredges from the canal or can be removed from the canal berm before it reaches the water section, by steam shovels and cars.

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[1] Not printed.

(*d*) While the blow sand is a menace and will need constant attention to prevent its encroachment upon the canal, our observations, while not extending over a sufficient time to lead to final conclusions, have, however, led us to the opinion that it is not an obstacle to the successful and economical operation of a large canal. At least two years will lapse before construction on this section can be undertaken, during which time further studies concerning the sand movement and methods to reduce their movement should be carried on.

CLASSIFICATION OF MATERIAL.

(*a*) From Laguna Dam to siphon drop the character of material is either shown where exposed by the excavation of the canal or in the abrupt faces of the bluffs just above the present canal prism or in the log of the original test pits. The rock is confined to the first 76 stations below the dam. The balance of this section is composed largely of sand, gravel, and loose rock, with some sand that is found well compacted. Below station 76 the material is of a character that can be handled by steam shovels or drag lines without the use of powder. From siphon drop to Araz 11 test pits were put down several years ago on or near the line of the proposed canal, by the Reclamation Service. These show the material to be sand, gravel, and compacted sand, all of which can be handled with steam shovels and drag lines without the use of powder. From Araz to a mile west of the west edge of the sand hills during the last 14 months a number of test pits were put down at frequent intervals, mostly in the bottom of the washes, the material in the ridges being as a rule exposed on the steep slopes and also in the cuts of the Southern Pacific and Inter-California Railroads. Some drifting into the steep side of the ridges was done in order to expose the material in place. West of the point south of the westerly point of Pilot Knob the locations of the test pits were selected in open places on the mesa floor between the sand dunes. On this portion the distance between the pits was about 1 mile near Pilot Knob, up to more than 2 miles toward the west side of the sand hills. In 1913 the Imperial Irrigation District put down three test pits through the sand hills along the international boundary, and in 1918 the Imperial Laguna Water Co. put down several more along the same line. These test pits all showed the same general character of material as those described below through the sand hills.

(*b*) The material from Araz to the high rocky ridge at Pilot Knob is composed of sand, gravel, compacted sand, and cemented gravel. The high rocky ridge at Pilot Knob, 600 feet across, is a spur of the main mountain extending to the east, on the eastern end of which is located the Imperial Irrigation District's quarry.

(*c*) From the above ridge southwest to the international boundary and thence along the boundary to a point south of the western edge of Pilot Knob the material is sand, gravel, compacted sand, and cemented gravel. From this latter point to a point a mile west of the western edge of the sand hills the material is sand and gravel, the major part of which is very loose. Only in a small portion of the total depth of holes put down in the blow sand area would the material stand even a few inches in height without cribbing. A portion of the compacted sand and cemented gravel from Araz to and around Pilot Knob will require the use of powder to loosen up for steam shovels or drag-line excavation.

(*d*) The material below the mesa floor through the sand hills contains sufficient gravel and coarse sand so that there is no danger of it drifting from the spoil banks. The test pits are shown on the profile (see Exhibit B).

CANAL SECTIONS AND CAPACITIES.

(*a*) With a duty of 1 second-foot to 100 acres, the above area of 900,000 acres will require a diversion of 9,000 second-feet in addition to the amount required for the Yuma project of 1,600 second-feet, or a total of 10,600 second-feet from Laguna Dam to siphon drop.

(*b*) All the larger sections of the canal were designed to give a velocity of 3.5 feet per second when running at capacity and 2.5 feet per second or better when running at half capacity.

(*c*) Below are given some of the dimensions of principal cross sections of the canal. The different cross sections are shown on the profile. These are numbered with identical numbers for the cross section and on the profile, showing the portion of the canal to which it is applicable (see Exhibit B).

1. The canal from Laguna Dam to siphon drop will have a bottom width of 162 feet, a water depth of 16 feet, side slopes of 2 to 1 on the river side and 1½ to 1 on the land side, a gradient of 0.0000792, and an estimated carrying capacity of 10,600 second-feet.

2. From siphon drop to the sand hills, the bottom will vary from 146 to 154 feet, with water depth 15 feet, side slopes from 1½ to 1 to 2 to 1, a gradient of 0.0000786 to 0.0000862, and an estimated carrying capacity of not less than 9,000 second-feet. The different widths, side slopes, and gradients are due to different cross sections adopted to fit the varying character of the material to be excavated.

3. Through the sand hills the bottom width is 140 feet, water depth 15 feet, side slopes 2 to 1, with a berm of 30 feet on either side at the surface of the mesa floor, which is the base of the sand dunes, a gradient of 0.0000813, and an estimated carrying capacity of 9,000 second-feet.

4. From the west side of the sand hills to mesa canal No. 1 the dimensions are the same as those used from siphon drop to the sand hills.

5. From mesa canal No. 1 to mesa canal No. 2 the bottom width is 125 feet, water depth 12 feet, side slopes 1½ to 1, gradient 0.00012, and estimated carrying capacity of 6,000 second-feet.

6. From mesa canal No. 2 to the east main canal, a bottom width of 113 feet, a water depth of 12 feet, side slopes 1½ to 1, a gradient of 0.00012, and an estimated carrying capacity of 5,502 second-feet.

7. From the east main canal to near Allison heading, a bottom width of 108 feet, a water depth of 10.5 feet, side slopes 1½ to 1, a gradient of 0.00014, and an estimated carrying capacity of 4,546 second-feet.

8. From near Allison heading to the Alamo River, a bottom width of 95.5 feet, a water depth of 10 feet, side slopes 1½ to 1, a gradient of 0.000156, and an estimated carrying capacity of 3,797 second-feet.

9. From the Alamo River to the central main canal, a bottom width of 82 feet, a water depth of 9.5 feet, side slopes 1½ to 1, a gradient of 0.00017, and an estimated carrying capacity of 3,199 second-feet.

10. From the central main canal to the west-side main canal, a bottom width of 46.5 feet, a water depth of 8 feet, side slopes 1½ to 1, a gradient of 0.0002, and an estimated carrying capacity of 1,495 second-feet.

(*d*) No reductions in the size of the canal cross sections have been made, due to the probable losses in the canal from seepage for the reason heretofore given. The canal banks are designed to have a 6-foot freeboard, 30-foot crowns, and a river slope of 1½ to 1 from Laguna Dam to the deep cuts southwest of Pilot Knob.

CANAL STRUCTURES.

(*a*) All the canal structures are planned to be of concrete and steel. The approximate location of the several structures is shown upon the general map of the all-American canal (see Exhibit A). The cost of the several structures is given under the heading "Estimates of cost." General plans of some of the principal structures are given in the exhibits.[1] These are shown to represent types of the several structures as well as specific structures.

(*b*) *Laguna Dam and sluiceway improvements.*—It is contemplated to raise the crest of Laguna Dam 2 feet, except that a section from 600 to 800 feet will be left from 1 to 2 feet lower, to act as a sluiceway and training channel for the river. This section will be closed by temporary flashboards during low water. Exhibit C shows a section of this proposed change in the crest of the dam. The plan for the enlarged settling basin, sluiceway, and canal heading is shown on the same exhibit. An additional Stoney gate of the same type and size as those now in place is to be added.

(*c*) *Waste gates.*—A waste gate of the Stoney type will be located at a point between the canal heading and station 64, of sufficient capacity to drain the canal. Waste gates of the same type are provided at Araz and Pilot Knob. Other waste gates of a lighter type will be provided at the Alamo and New River crossings.

(*d*) *Checks.*—Checks are provided below all the principal turnouts, of a general type shown in Exhibit F.[1] Below mesa canal No. 2 the water elevation will be controlled by the siphon spillway located at power plant No. 2.

(*e*) The turnouts vary a great deal in the amount of water that will be required for the different distributing laterals.

(*f*) The two larger drops are located at power plants Nos. 1 and 2. Siphon spillways are designed for these locations, in order to maintain a constant head at the power plant. The smaller drops are of the inclined-chute type. The 6-foot drop 3 miles above power plant No. 1 may in the future be added to the drop at power plant No. 1 by raising the banks of the canal. No provision, however, has been made for this future work in the estimates.

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[1] Not printed.

UNIT COSTS.

In arriving at unit costs for this work, in consultation with the board of engineers, it was decided that costs should be based upon what this class of work would cost under present conditions with standard equipment now in use upon work of like magnitude. The unit prices adopted and used are as follows:

Earth excavation:			
Laguna Dam to Pilot Knob	per cubic yard		$0.20
Pilot Knob through sandhill section	do.		.30
For mesa (cuts less than 35 feet)	do.	$0.18–	.20
For structures	do.		.50
Earth back fill:			
Dry	do.		.50
Puddle	do.		1.00
Rock excavation	do.		.75
Concrete:			
Massive	do.		15.00
Formed	do.		18.00
Formed in power plants and siphon spillways [1]	do.		27.00
Alamo and New River flumes	do.		20.00
Lining	do.		13.50
Canal lining (4 inches thick)	per square foot		.17
Rock paving	per cubic yard		2.00
Reinforcing steel in place	per pound		.07
Right of way	per acre		100.00
Engineering and contingencies	per cent		15

ESTIMATES OF COST.

(*a*) Estimates of cost given below are based upon the unit costs given above and the type of structures here indicated and shown. Other data that it will be necessary to obtain before final construction can be undertaken may change the sizes of some of the structures and may modify the type here given. However, it has been the object to make a cost estimate upon some definite type that is deemed permanent and upon which quantities could be ascertained for an estimate.

(*b*) First, an estimate is made for a canal to divert 10,600 second-feet at Laguna Dam to serve the Yuma project, the Imperial Irrigation District, and the new lands which can economically be served.

(*c*) Second, an estimate for a canal of 7,600 second-feet at Laguna Dam to serve the Yuma project and the Imperial Irrigation District. In this estimate the structures have been estimated of a size and capacity sufficient for the development of 10,600 second-feet. Only such structures as would be required solely for the larger development are omitted.

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[1] Including reinforcing.

(*d*) As a first alternative under (*b*) a concrete-lined section has been estimated through the deep cut from Pilot Knob through the blow sand.

(*e*) As a second alternative under (*b*) a concrete-lined section with a depressed grade of 1.3 feet has been estimated through the deep cut from Pilot Knob through the sand hills. The objections to a concrete-lined canal at this time are: First, that it does not readily admit of enlargement; and, second, there may be more or less settlement due to the surrounding ground becoming wet for the first time. The last estimate mentioned above is for the purpose of providing 1,600 second-feet additional capacity through the lined section without changing the elevation of the water surface at Laguna Dam over that contemplated in estimate under (*b*).

(*f*) The division of costs between the Reclamation Service (for the Yuma project) and the Imperial Irrigation District for the enlargement of the diversion works at Laguna Dam, the enlargement of the Yuma main canal from Laguna Dam to siphon drop and the construction of a new canal from this latter point to the proposed power plant of the Reclamation Service near Araz is fixed by the contract of October 23, 1918, between the Secretary of the Interior, and Imperial Irrigation District. These ratios under the abovementioned contract are as follows: For a canal of 10,600 second-feet capacity at Laguna Dam, the Yuma project will pay two-ninths and the Imperial Irrigation District seven-ninths of the cost of enlargement. For a canal of 7,600 second-feet capacity at Laguna Dam, the Yuma project will pay one-third and the Imperial Irrigation District two-thirds of the cost of enlargement. This division of cost is taken into account in the final analysis. In the development of a diversion capacity of 7,600 second-feet, the canal structures are designed for the full development of 10,600 second-feet. In order to obtain the amounts the several interests should pay, the costs of excavation and structures should be divided on a different basis, in accordance with the provision of the contract of October 23, 1918. This will leave an investment for the benefit of the new lands which will come under the project in the future. For the carrying of this investment some agreement must be reached between the Government and the Imperial Irrigation District prior to the beginning of construction and until the new lands assume the indebtedness. The same principles must be applied from Araz to the points of bifurcation where the new lands will take their water. In this case, however, there is no contract fixing the methods of apportioning the costs between the new lands and the Imperial Irrigation District. For the purpose of arriving at the cost apportionment between the Imperial Irrigation District and the new lands it is assumed that these costs would be apportioned on the acreage basis, or about 60 per cent for the Imperial Irrigation District and 40 per cent for the new lands. The above ratios are applicable to the point where the first and main diversion is made for the new lands. As only one-seventh of the water for the new lands is carried through the section from mesa canal No. 1 to mesa canal No. 2 the ratios for the division of the costs should be 93⅓ per cent for the Imperial Irrigation District and 6⅔ per cent for the new lands.

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District and additional mesa lands with 1,600 second-feet additional capacity for Yuma project down to siphon drop.

(Laguna Dam to siphon drop, canal capacity of 10,600 second-feet.)

Excavation:		
Earth, 5,045,000 cubic yards, at 20 cents	$1,009,000	
Rock, 754,600 cubic yards, at 75 cents	565,950	
Total	1,574,950	
15 per cent contingency	236,242	
		$1,811,192
Structures:		
Alterations at Laguna Dam (see Exhibit C)	745,000	
Sluice about 1¼ miles below dam	240,000	
Turnout reservation canal	10,500	
Check below turnout reservation canal	27,500	
Picacho road bridge	34,000	
Raising siphon drop	20,000	
Walapai lateral turnout	7,100	
Check below siphon drop	22,000	
Paved overflow for receiving storm waters into the canal	20,000	
10 miles of telephone line	2,250	
Total	1,128,350	
15 per cent contingency	169,252	
		1,297,602
Cost of connecting with Laguna Dam (estimated under contract of Oct. 23, 1918)		1,900,000
Total		5,008,794

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District and additional mesa lands.

(Siphon drop to Araz, 9,000 second-foot canal).

Earth, 2,600,000 cubic yards, at 20 cents	$520,000	
Earth fill (raising railroad grade), 30,000 cubic yards, at 30 cents	9,000	
Raising and ballasting track 1 mile	6,000	
Concrete lining 4,400 feet of canal along railroad track 4 inches thick, 950,000 square feet, at 17 cents	161,500	
Total	696,500	
15 per cent contingency	104,475	
		$800,975

Structures:		
Highway bridge	$34,000	
Double-track railway bridge at Araz siding	85,000	
1 culvert for surface drainage	20,000	
Highway bridge	34,000	
Wasteway	235,000	
Check	22,000	
Highway bridge	34,000	
Paved overflow for receiving storm waters into the canal	20,000	
5 miles telephone line	1,125	
Total	485,125	
15 per cent contingency	72,769	
		$557,894
Grand total		1,358,869

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District and additional mesa lands.

(Araz to upper power site, Pilot Knob, opposite Rockwood gate, 9,000 second-foot canal.)

Excavation:		
Earth, 805,000 cubic yards, at 20 cents	$161,000	
Rock, 145,000 cubic yards, at 75 cents	108,750	
Concrete lining 400 feet canal, 86,400 square feet, at 17 cents.	14,688	
Total	284,438	
15 per cent contingency	42,666	
		$327,104
Structures:		
Sluiceway [1]	325,000	
Check [1]	22,000	
Highway bridge	34,000	
2 culverts for surface drainage	40,000	
1½ miles telephone	340	
Total	421,340	
15 per cent contingency	63,201	
		484,541
Grand total		811,645

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District and additional mesa lands.

(Upper power site, Pilot Knob, opposite Rockwood gates, to Pilot Knob, 9,000 second-foot canal.)

Excavation:		
Earth, 1,122,000 cubic yards, at 20 cents	$224,400	
Rock, 1,318,000 cubic yards, at 75 cents	988,500	
Total	1,212,900	
15 per cent contingency	181,935	
		$1,394,835

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[1] Structures to be located at place selected for power site or permanent wasteway (see Power development, p. 97).

Structures:		
Railroad bridge	$45,000	
Culvert for surface drainage	20,000	
1½ miles telephone line	340	
Total	65,340	
15 per cent contingency	9,801	$75,141
Grand total		1,469,976

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District and additional mesa lands.

(Pilot Knob to east-side mesa canal No. 1 (station 1525), 9,000 second-foot canal.)

Excavation:		
Earth, 46,736,000 cubic yards, at 30 cents	$14,020,800	
Earth, 1,770,000 cubic yards, at 20 cents	354,000	
Blow sand, 500,000 cubic yards,[1] at 30 cents	150,000	
Rock, 312,000 cubic yards, at 75 cents	234,000	
Total	14,758,800	
15 per cent contingency	2,213,820	$16,972,620
Structures:		
East mesa canal No. 1 turnout	24,000	
Drop and check	52,000	
26 miles telephone line	5,850	
Total	81,850	
15 per cent contingency	12,277	94,127
Total		17,066,747

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District and additional mesa lands.

(Mesa canal No. 1 to mesa canal No. 2, 6,000 second-foot canal.)

Excavation:		
Earth, 2,344,556 cubic yards, at 18 cents	$422,020	
15 per cent contingency	63,303	$485,323
Structures:		
30-foot siphon spillway for operation with power plant	88,740	
Turnout for mesa canal No. 2	10,000	
5-mile telephone line	1,125	
Total	99,865	
15 per cent contingency	14,980	114,845
Grand total		600,168

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[1] Estimate of amount of sand that will blow in during construction.

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District and additional mesa lands.

(Mesa canal No. 2 to west-side main canal, 5,500 to 1,500 second-foot canal.)

Excavation:		
Earth, 6,836,400 cubic yards, at 18 cents	$1,230,552	
15 per cent contingency	184,583	$1,415,135
Structures:		
47-foot siphon spillway for operation with power plant No. 2.	96,100	
Turnout	14,000	
Check	11,000	
Drop	28,000	
Turnout	10,000	
Wasteway to Alamo River	44,000	
Check	9,000	
Flume across Alamo River	116,000	
Turnout	700	
Check	9,500	
Drop	26,500	
Turnout	5,500	
Do	18,000	
Check	5,700	
Drop	8,500	
Do	14,000	
Wasteway at New River	130,000	
Check	4,000	
Flume across New River	781,000	
Turnout	6,000	
Check	4,000	
Drop	8,500	
5 highway bridges near Calexico	52,500	
Highway bridge, station 2350	21,000	
Highway bridge, station 2690	14,000	
Railroad bridge at Calexico	15,500	
Right of way	125,000	
35 miles telephone line	7,875	
Total	1,585,875	
15 per cent contingency	237,882	1,823,757
Grand total		3,238,892

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District and additional mesa lands with 1,600 second-feet additional capacity for Yuma project down to siphon drop (10,600 to 1,500 second-feet).

RECAPITULATION.

Laguna Dam to siphon drop	$5,008,794
Siphon drop to Araz	1,358,869
Araz to upper power site, Pilot Knob	811,645
Upper power site to Pilot Knob	1,469,976
Pilot Knob to east-side mesa canal No. 1	17,066,747
Mesa canal No. 1 to mesa canal No. 2	600,168
Mesa canal No. 2 to west-side main canal	3,238,892
Total	29,555,091

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District and additional mesa lands with 1,600 second-feet additional capacity for Yuma project down to siphon drop (10,600 to 1,500 second-feet).

DIVISION OF COSTS

1. Between the Yuma project for power development and the Imperial Irrigation District, including the new lands:		
Laguna Dam to siphon drop	$5,008,794	
Siphon drop to Araz	1,358,869	
		$6,367,663
Less connection with Laguna Dam (estimated under contract Oct. 23, 1918)		1,900,000
Amount to be apportioned between the Yuma project and the Imperial Irrigation District		4,467,663
For the Yuma project, two-ninths (contract Oct. 23, 1918)	992,814	
For the Imperial Irrigation District, seven-ninths (contract Oct. 23, 1918)	3,474,849	
		4,467,663
2. Between the Imperial Irrigation District and the new lands:		
Laguna Dam to Araz (seven-ninths above)	3,474,849	
Connection with Laguna Dam (above)	1,900,000	
Araz to upper power site (Pilot Knob)	811,645	
Upper power site to Pilot Knob	1,469,976	
Pilot Knob to east-side mesa canal No. 1	17,066,747	
		24,723,217
60 per cent apportioned to Imperial Irrigation District	14,833,930	
40 per cent apportioned to new lands	9,889,287	
		24,723,217
East-side mesa canal No. 1 to mesa canal No. 2		600,168
93⅓ per cent apportioned to Imperial Irrigation District	560,157	
6⅔ per cent apportioned to new lands	40,011	
		600,168
3. Summation of costs to different interests:		
The Yuma project		992,814
The Imperial Irrigation District—		
60 per cent apportioned above	14,833,930	
93⅓ per cent apportioned above	560,157	
Mesa canal No. 2 to west-side main canal	3,238,892	
		18,632,979
The new lands—		
40 per cent apportioned above	9,889,287	
6⅔ per cent apportioned above	40,011	
		9,929,298
Total		29,555,091

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District with 1,600 second-feet additional capacity for Yuma project down to siphon drop.

(First alternative: Pilot Knob to mesa canal No. 1, 9,000 second-feet canal.)

A first alternative estimate was made to provide a concrete-lined section through the sand hills. The concrete lining is to be 4 inches thick and extend 2 feet above the high-water line. The following are the principal hydraulic functions:

Bottom width	feet		70
Depth	do		15
Side slopes			2 to 1
Gradient			0.00017
Velocity	feet per second		6
Discharge	second-feet		9,000
Excavation:			
Earth, 40,736,000 cubic yards, at 30 cents		**$12,220,800**	
Earth, 1,770,000 cubic yards, at 20 cents		**354,000**	
Blow sand, 500,000 cubic yards,[1] at 30 cents		**150,000**	
Rock, 312,000 cubic yards, at 75 cents		**234,000**	
Concrete lining, 10,278,000 square feet, at 17 cents		**1,747,260**	
Total		14,706,060	
15 per cent contingency		2,205,909	
			$16,911,969
Structures:			
East mesa canal No. 1 turnout		24,000	
26 miles of telephone		5,850	
Total		29,850	
15 per cent contingency		4,477	
			34,327
Grand total			16,946,296

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District with 1,600 second-feet additional capacity for Yuma project down to siphon drop.

(Second alternative: Pilot Knob to mesa canal No. 1, 10,600 second-feet canal.)

A second alternative estimate was made to provide a concrete-lined section through the sand hills, but with a deeper section than the first alternative estimate, in order to give an additional capacity of 1,600 second-feet. The concrete lining is to be 4 inches thick and extend 2 feet above the high-water line. The following are the principal hydraulic functions:

Bottom width	feet	70
Depth	do	16.3
Side slope		2 to 1
Slope		0.00017
Velocity	feet per second	6.35
Discharge	second-feet	10,600

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[1] **Estimated amount of sand that will blow in during construction.**

Excavation:		
Earth, 43,605,000 cubic yards, at 30 cents	$13,081,500	
Earth, 1,770,000 cubic yards, at 20 cents	354,000	
Blow sand,[1] 500,000 cubic yards, at 30 cents	150,000	
Rock, 312,000 cubic yards, at 75 cents	234,000	
Concrete lining, 10,792,000 square feet, at 17 cents	1,834,640	
Total	15,654,140	
15 per cent contingency	2,348,121	
		$18,002,261
Structures:		
East mesa canal No. 1 turnout	24,000	
26 miles telephone	5,850	
Total	29,850	
15 per cent contingency	4,477	
		34,327
Grand total		18,036,588

The above alternative estimates include the extra excavation from the west side of the sand hills to station 1575, due to the canal being in deeper cut because of the increased slope of the concrete-lined section. The 6-foot drop at station 1575 will just be eliminated by the greater gradient. This, however, will lower the elevation of the east mesa canal No. 1, 6 feet, and thus eliminate a certain acreage on the east-side mesa that can not be served by gravity. It will also reduce the possible head at mesa power station No. 1 from 30 to 24 feet. Alternative No. 1 decreases the cost, $120,451 over a canal built in an earth section. Alternative No. 2 increases the cost $969,841 over a canal built in an earth section. The estimated cost of the other sections of the canal will remain the same as in the first estimate and are, therefore, not repeated above. In the second alternative estimate, future enlargements of the earth sections are anticipated but not covered in this estimate.

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District with 1,600 second-feet additional capacity for Yuma project down to siphon drop.

(Laguna Dam to siphon drop, 7,600 second-foot canal.)

Excavation:		
Earth, 3,570,920 cubic yards at 20 cents	$714,184	
Rock, 542,300 cubic yards at 75 cents	406,725	
Total	1,120,909	
15 per cent contingency	168,136	
		$1,289,045
Structures:		
Alterations at Laguna Dam (see Exhibit C)	745,000	
Sluice about 1¼ miles below Dam	240,000	
Turnout, reservation canal	10,500	
Check below turnout, reservation canal	27,500	
Picacho road bridge	34,000	
Raising siphon drop	20,000	

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[1] Estimated amount of sand that will blow in during construction.

Structures—Continued.		
Walapai lateral turnout	$7,100	
Check below siphon drop	22,000	
Paved overflow for receiving storm waters into the canal.	20,000	
10 miles of telephone line	2,250	
Total	1,128,350	
15 per cent contingency	169,252	$1,297,602
Imperial Valley cost of connecting with Laguna Dam (contract of Oct. 23, 1918)		1,600,000
Grand total		4,186,647

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District.

(Siphon drop to Araz, 6,000 second-foot canal.)

Excavation:		
Earth, 2,300,000 cubic yards at 20 cents	$460,000	
Earth fill (raising railroad grade), 30,000 cubic yards at 30 cents	9,000	
Raising and ballasting 1 mile of track	6,000	
Concrete lining 4,400 feet of canal along railroad track 4 inches thick, 950,000 square feet at 17 cents	161,500	
Total	636,500	
15 per cent contingency	95,475	$731,975
Structures:		
3 highway bridges	102,000	
Double-track railroad bridge at Araz siding	85,000	
1 culvert for surface drainage	20,000	
Wasteway	235,000	
Check	22,000	
Paved overflow for receiving storm water into canal	20,000	
5 miles telephone line	1,125	
Total	485,125	
15 per cent contingency	72,769	557,894
Grand total		1,289,866

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District.

(Araz to upper power site, Pilot Knob, opposite Rockwood gates, 6,000 second-foot canal.)

Excavation:		
Earth, 504,000 cubic yards at 20 cents	$100,800	
Rock, 109,000 cubic yards at 75 cents	81,750	
Concrete lining 400 feet canal 4 inches thick, 74,400 square feet at 17 cents	12,648	
Total	195,198	
15 per cent contingency	29,280	$224,478

Structures:		
Sluiceway[1]	$325,000	
Check[1]	22,000	
Highway bridge	34,000	
2 culverts for surface drainage	40,000	
1½ miles telephone	340	
Total	421,340	
15 per cent contingency	63,201	
		$484,541
Grand total		709,019

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District.

(Upper power site, Pilot Knob, opposite Rockwood gates, to Pilot Knob, 6,000 second-foot canal.)

Excavation:		
Earth, 702,000 cubic yards, at 20 cents	$140,400	
Rock, 982,000 cubic yards, at 75 cents	736,500	
Total	876,900	
15 per cent contingency	131,535	
		$1,008,435
Structures:		
Railroad bridge	45,000	
Culvert for surface drainage	20,000	
1½ miles telephone line	340	
Total	65,340	
15 per cent contingency	9,801	
		75,141
Grand total		1,083,576

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District.

(Pilot Knob to west side main canal, 6,000 to 1,500 second-foot canal.)

Excavation:		
Earth, stations 385 to 470, 1,663,000 cubic yards, at 20 cents	$332,600	
Earth, stations 470 to 1525, 43,820,000 cubic yards, at 30 cents	13,146,000	
Earth, station 1525 to end, 9,216,000 cubic yards, at 18 cents	1,658,880	
Blow sand,[2] 500,000 cubic yards, at 30 cents	150,000	
Rock, 294,000 cubic yards, at 75 cents	220,500	
Total	15,507,980	
15 per cent contingency	2,326,197	
		$17,834,177

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[1] Structures to be located at place selected for power site or permanent wasteway (see "Power development," p. 97).

[2] Estimate of amount of sand that will blow in during construction.

Structures:		
24-foot siphon spillway for operation with power plant No. 1[1]	$88,740	
47-foot siphon spillway for operation with power plant No. 2	96,100	
Turnout	14,000	
Check	11,000	
Drop	28,000	
Turnout	10,000	
Wasteway at Alamo River	44,000	
Check	9,000	
Flume across Alamo River	116,000	
Turnout	700	
Check	9,500	
Drop	26,500	
Turnout	5,500	
Turnout	18,000	
Check	5,700	
Drop	8,500	
Drop	14,000	
Wasteway at New River	130,000	
Check	4,000	
Flume across New River	781,000	
Turnout	6,000	
Check	4,000	
Drop	8,500	
5 highway bridges near Calexico	52,500	
Highway bridge, station 2350	21,000	
Highway bridge, station 2690	14,000	
Railroad bridge at Calexico	15,500	
Right of way	125,000	
66 miles of telephone line	14,850	
Total	1,681,590	
15 per cent contingency	252,238	
		$1,933,828
Grand total		19,768,005

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District with 1,600 second-feet additional capacity for Yuma project down to siphon drop (7,600 to 1,500 second-feet).

RECAPITULATION.

Laguna Dam to siphon drop	$4,186,647
Siphon drop to Araz	1,289,869
Araz to upper power site, Pilot Knob	709,019
Upper power site to Pilot Knob	1,083,576
Pilot Knob to west-side main canal	19,768,005
Total	27,037,116

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[1] Constructed for full development as far as possible. Will cost about same as though built full height

Estimate for construction of all-American canal of capacity to serve the Imperial Irrigation District, with 1,600 second-feet additional capacity for Yuma project down to siphon drop (7,600 to 1,500 second-feet).

DIVISION OF COSTS.

1. Between the Yuma project for power development and the Imperial Irrigation District, including interest of new lands in structures:		
Laguna Dam to siphon drop, excavation	$1,289,045	
Siphon drop to Araz, excavation	731,975	
		$2,021,020
Amount to be apportioned between the Yuma project and the Imperial Irrigation District—		
For the Yuma project, one-third (contract Oct. 23, 1918)	673,673	
For the Imperial Irrigation District, two-thirds (contract Oct. 23, 1918)	1,347,347	
		2,021,020
Laguna Dam to siphon drop, structures	1,297,602	
Siphon drop to Araz, structures	557,894	
		1,855,496
Amount to be apportioned between the Yuma project and the Imperial Irrigation District—		
For the Yuma project, two-ninths (contract Oct. 23, 1918)	412,332	
For the Imperial Irrigation District, seven-ninths (contract Oct. 23, 1918)	1,443,164	
		1,855,496
2. Between the Imperial Irrigation District and the new lands, structures only:		
Connecting with Laguna Dam (contract Oct. 23, 1918)	1,600,000	
Laguna Dam to Araz (seven-ninths above)	1,443,164	
Araz to upper power site, Pilot Knob	484,541	
Upper power site to Pilot Knob	75,141	
		3,602,846
60 per cent apportioned to the Imperial Irrigation District	2,161,708	
40 per cent apportioned to the new lands	1,441,138	
		3,602,846
24-foot siphon spillway for operation with power plant No. 1		88,740
93⅓ per cent apportioned to the Imperial Irrigation District	82,824	
6⅔ per cent apportioned to the new lands	5,916	
		88,740
3. Summation of costs to different interests:		
The Yuma project—		
One-third apportioned on excavation above	673,673	
Two-thirds apportioned on structures above	412,332	
		1,086,005
The new lands—		
40 per cent apportioned on structures above	1,441,138	
6⅔ per cent apportioned on structures above	5,916	
		1,447,054
The Imperial Irrigation District—		
Total cost		27,037,116
Less amount apportioned to Yuma project, as given above	1,086,005	
Less amount apportioned to new land, as given above	1,447,054	
		2,533,059
Net cost to Imperial Irrigation District		24,504,057

POWER DEVELOPMENT.

(*a*) Plans are made for a temporary or construction power plant at or near Pilot Knob, where a drop of about 30 feet can be obtained by discharging the water into the Imperial Canal. This power plant should be constructed and made available for the generation of power at as early a date as possible in order to furnish cheap power for construction purposes. The plans are for the development of two units of 4,500 turbine horsepower each, with provision for adding a third unit of the same size. In the preliminary report the temporary power plant was located at the lower or south end of the rock cut at Pilot Knob. Since that report was made another site nearly opposite the Rockwood gate has also been investigated. Test pits at both sites have been put down as deep as possible without resorting to pumping of the water. The tailrace of the upper one of these sites would discharge into the Imperial Canal between the Rockwood and Hanlon gates. The tailrace from the lower site will discharge into the Imperial Canal below Hanlon gate. It is as yet a question which of these sites should be developed. If developed at the upper site and a siphon spillway used to regulate the flow in conjunction with the power house and later a sluice gate located at the lower power site were constructed, considerable heavy construction work would be avoided until after the upper portion of the system could be placed in operation and electric power generated. This would give an estimated expenditure of $4,880,258 for canal construction from Laguna Dam after deducting the following items from the first three items under "Recapitulation" (p. 89):

Cost of connecting with Laguna Dam	$1,900,000
Sluiceway and check	347,000
15 per cent contingency on above	52,050
Total deduction	2,299,050

To which should be added:

Construction power plant	$704,920
Tailrace	95,080
Total	800,000

Making total expenditure of $5,680,258.

(*b*) West of the sand hills there are two drops where it is planned to develop power. These we have called power plant No. 1 and power plant No. 2.

(*c*) At power plant No. 1, which is located 4 miles west of the east-side mesa canal, there is a fall of 24 feet. Three miles east of this power site there is a drop of 6 feet, which may in the future be carried downstream to power plant No. 1 by raising the canal banks and the structures at the power plant, giving a total fall of 30 feet. The plans at this site are for the development of 4 units of 4,500 turbine horsepower each.

(*d*) Power plant No. 2 is situated 5 miles west of power plant No. 1. At this site a head of 47 feet can be obtained. The plans are for the development of 4 units of 6,500 turbine horsepower each.

(*e*) The above developments are for the maximum capacity of the canals. At power plants Nos. 1 and 2 the discharge during the minimum flow of the river may fall to 20 or 25 per cent of the maximum capacity. This will limit the amount of power available for commercial purposes after deducting the amount required by the Yuma project and Imperial Irrigation District for operating purposes and pumping at the period of minimum discharge.

(*f*) It is planned that the power equipment installed in the construction power plant at Pilot Knob will be used in power plants Nos. 1 and 2. The first plant will be built entirely for construction purposes. Credit has been given in the estimate for the machinery that will be transferred to the other plants. Therefore the cost of the plant given below should be depreciated within the period covered by construction and charged to the cost of furnishing power for construction purposes.

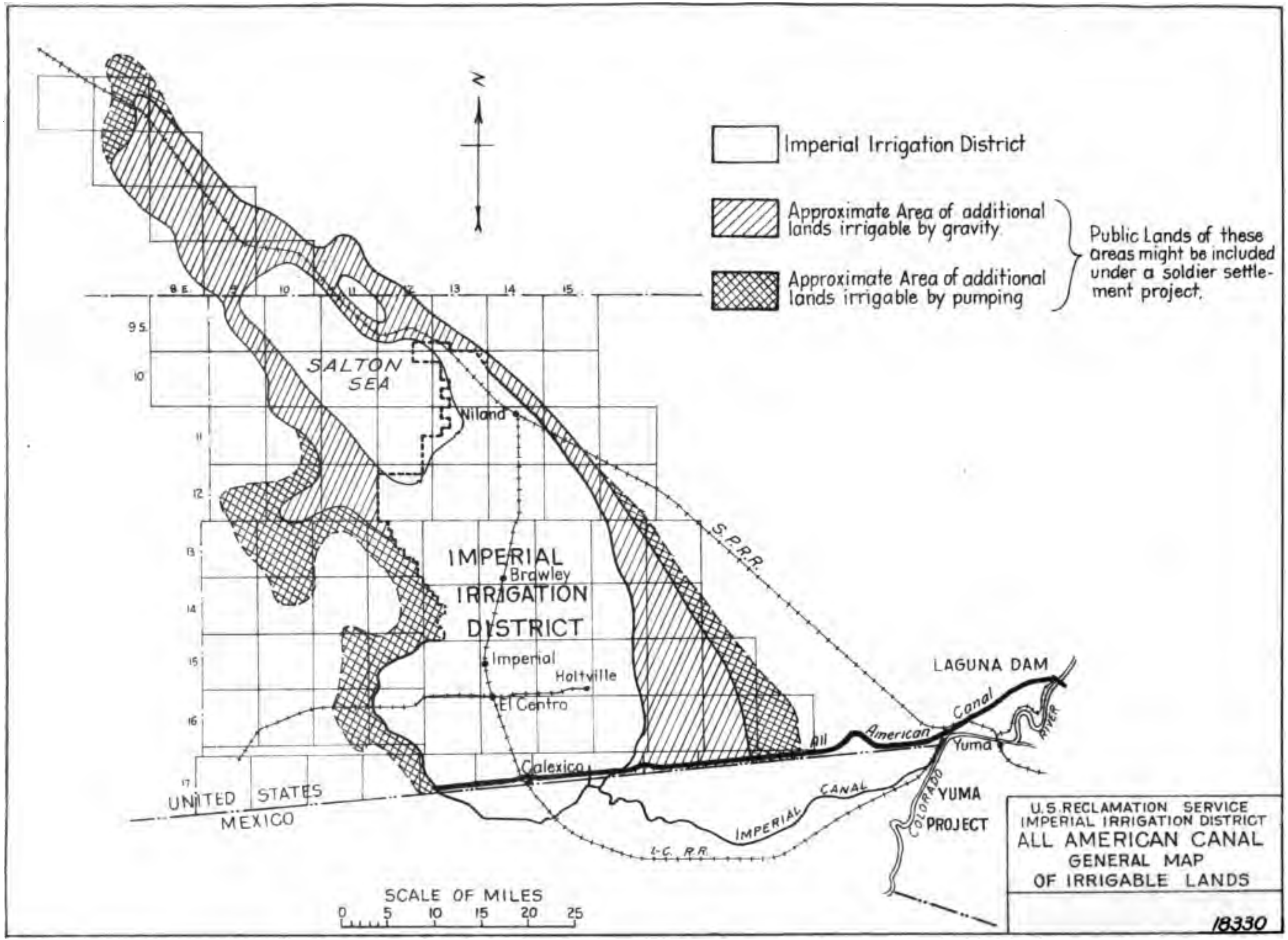
(*g*) The estimated cost of developing the power plants without transmission lines is as follows:

Estimated cost of power development.

Item.	Power plant No. 1.	Power plant No. 2.	Construction power plant.
Preparatory work	$48, 610	$48, 030	$43, 520
Excavating	3, 670	4, 800	7, 970
Buildings and foundations	148, 970	220, 520	72, 530
Machinery	786, 020	1, 057, 130	388, 000
Draft tubes, grillage, and trash boom	14, 680	18, 010	4, 750
Gates and hoists	19, 220	21, 760	12, 320
Siphon spillway	(1)	(1)	74, 840
Switch yard	13, 280	13, 280	....
Settling basin and cooling tower	2, 530	2, 530	3, 390
Operators' quarters	22, 610	22, 610	5, 650
Improvement to grounds	11, 300	11, 300	....
Total	1, 070, 890	1, 419, 970	612, 970
15 per cent contingency	160, 633	212, 995	91, 950
	1, 231, 523	1, 632, 965	704, 920
Credit for machinery used	....	....	182, 140
Total cost of plants	1, 231, 523	1, 632, 965	522, 780

[1] Charged into canal construction.

PORTER J. PRESTON, *Engineer.*



U.S. RECLAMATION SERVICE
IMPERIAL IRRIGATION DISTRICT
ALL AMERICAN CANAL
GENERAL MAP
OF IRRIGABLE LANDS

18330

N
Imperial Irrigation District
Approximate Area of additional lands irrigable by gravity
Approximate Area of additional lands irrigable by pumping
Public Lands of these areas might be included under a soldier settlement project.
8 E.
9
10
11
12
13
14
15
9 S.
10
11
12
13
14
15
16
17
SALTON SEA
Niland
IMPERIAL IRRIGATION DISTRICT
Brawley
Imperial
Holtville
El Centro
Calexico
S.P.R.R.
LAGUNA DAM
All American Canal
Yuma
RIVER
COLORADO
YUMA PROJECT
IMPERIAL CANAL
I.-C. R.R.
UNITED STATES
MEXICO
SCALE OF MILES
0
5
10
15
20
25

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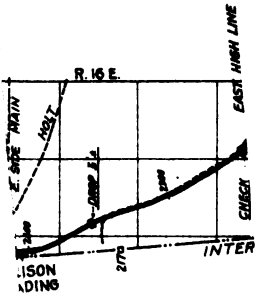

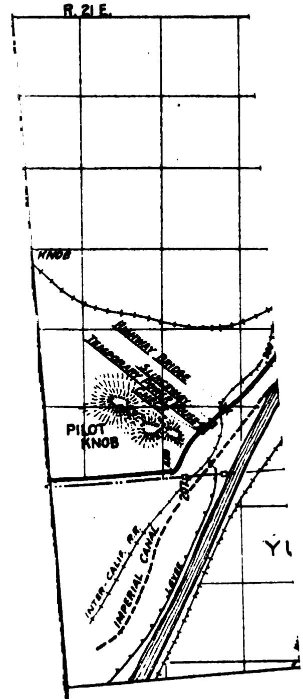

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EXHIBIT C

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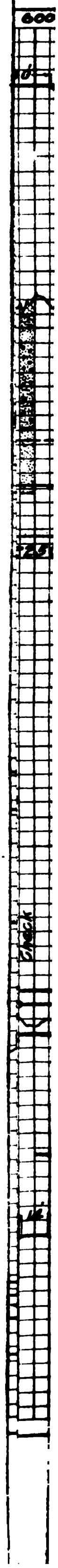
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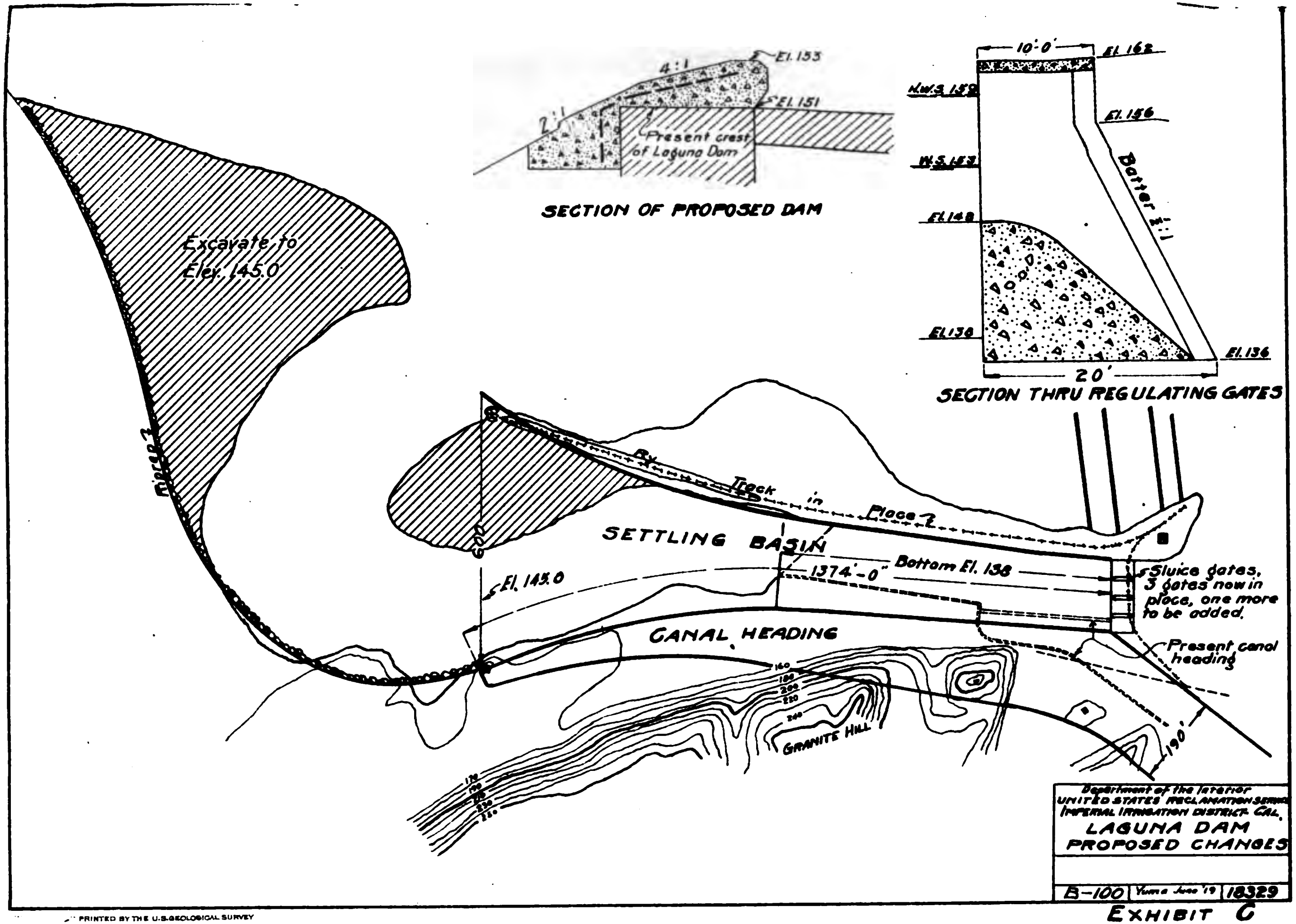

Department of the Interior
UNITED STATES RECLAMATION SERVIC
IMPERIAL IRRIGATION DISTRICT CAL.

LAGUNA DAM
PROPOSED CHANGES

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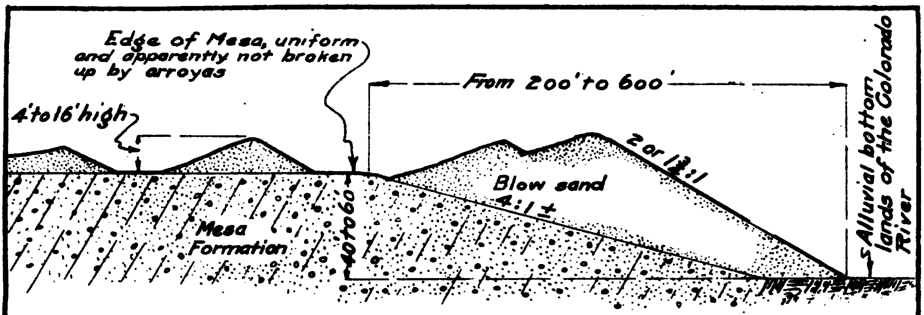
Edge of Mesa, uniform and apperently not broken up by arroyas
4'to16'high
From 200' to 600'
2 or 1½:1
Blow sand
4:1±
Mesa Formation
40 to 60
Alluvial bottom lands of the Colorado River

Fig. I

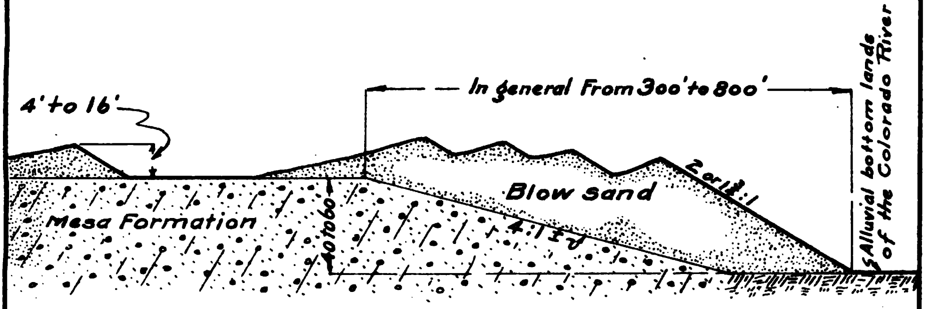
4' to 16'
In general From 300' to 800'
2 or 1½:1
Blow sand
4:1±
Mesa Formation
40 to 60
Alluvial bottom lands of the Colorado River

Fig. II

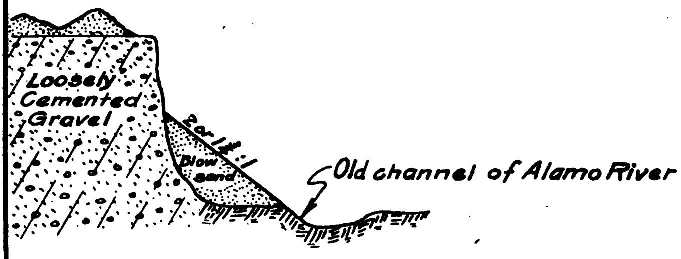

Fig. III

Department of the Interior
United States Reclamation Service
IMPERIAL IRRIGATION DISTRICT - CAL.
ALL AMERICAN CANAL
TYPICAL SECTIONS AT THE
SOUTH END OF SAND HILLS

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EXHIBIT D

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